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Evaluating Factors That Affect Construction Project Duration

by
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The actual duration of both military and civil works construction projects often differs substantially from the estimates made before construction begins. In fiscal year (FY) 1988, actual duration of military construction projects took an average of 17 percent longer than estimated. Similarly, actual duration of civil construction projects averaged 19 percent longer than estimated.

Automatically generated construction schedules may help to quickly produce more accurate estimates of construction duration. Such schedules will require improved activity duration estimates before the start of construction. Recent research has used flexible critical path method (CPM) schedules contained in an artificial intelligence (AI) based programming environment to create or update construction schedules. Durations for individual activities in these networks are based on material quantities, crew formations, and productivity rates, and on other types of building characteristics. When realistic activity durations have been developed, flexible logic between activities provides the basis for the CPM calculation of construction completion.

This study incorporates three additional factors that can unexpectedly extend construction activities: (1) work delays, (2) weather delays, and (3) productivity delays. The approach presented in this report may reduce the time required to produce preliminary schedules since the templates used here already contain a significant amount of scheduling knowledge.

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Automatically generated construction schedules may help to quickly produce more accurate estimates of construction duration. Such schedules will require improved activity duration estimates before the start of construction. Recent research has used flexible critical path method (CPM) schedules contained in an artificial intelligence (AI) based programming environment to create or update construction schedules. Durations for individual activities in these networks are based on material quantities, crew formations, and productivity rates, and on other types of building characteristics. When realistic activity durations have been developed, flexible logic between activities provides the basis for the CPM calculation of construction completion.

This study incorporates three additional factors that can unexpectedly extend construction activities: (1) work delays, (2) weather delays, and (3) productivity delays. The approach presented in this report may reduce the time required to produce preliminary schedules since the templates used here already contain a significant amount of scheduling knowledge.

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FOREWORD

This work was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A162734AT41, "Military Facilities Engineering Technology"; Work Unit SA-AF9 "Contract Duration Estimating System." The HQUSACE technical monitor was Mr. R. Oman, CEMP-CM.

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EVALUATING FACTORS THAT AFFECT CONSTRUCTION PROJECT DURATION

1 INTRODUCTION

Background

The actual duration of both military and civil works construction projects is often substantially different from the estimates or schedules made prior to initiation of construction. In fiscal year (FY) 1988, actual duration of military construction projects took an average of 17 percent longer than estimated.[*] Similarly, actual duration of civil construction projects averaged 19 percent longer than estimated.

More accurate estimates will require improved duration estimation and project schedule generation prior to the start of construction. Automatically generated construction schedules may provide the needed instrument to produce and update accurate construction schedules. The creation of artificial intelligence (AI) programming tools has contributed significantly to the research effort into the automatic generation of construction schedules.

Recent research studies[1] have used predetermined critical path method (CPM) schedules contained in an AI-based programming environment to create or update construction schedules. Durations for individual activities in these networks are based on material quantities, crew formations, and productivity rates, as well as on other types of building characteristics. To more accurately predict overall activity durations, additional factors that can unexpectedly extend construction activities must be found.

Once realistic activity durations have been developed, predetermined logic between activities provides the basis for the CPM calculation of construction completion. This is often done by developing networks at a detailed level of operation for very specific types of structures. Developing detailed durations can help create accurate schedules that are useful for project control activities.

Objectives

The overall objective of this project was to create an efficient system to produce a summary-level construction schedule. The specific objective of this part of the project was to identify the factors that may affect the individual activity durations or their sequence, and to outline how those factors influence construction activity durations and sequences.

Approach

A literature search was performed to determine factors that influence changes between initially estimated activity durations and actual durations. Contractors were interviewed to determine factors they perceived as most likely to alter estimated activity durations.

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* Reported in a briefing given by the Office of the Chief of Engineers (OCE) at Fort Belvoir, VA (c. October 1988).

1 T.J. Hindelang and J.F. Muth, "Dynamic Programming Algorithm for Decision CPM Networks," *Operations Research*, Vol 27, No. 2 (1975), pp 158-166; Ali Jaafari, "Criticism of CPM for Project Planning Analysis," *Journal of the Construction Engineering and Management*, Vol 110, No. 2 (American Society of Civil Engineers, June 1984).

Parameters used by the Corps of Engineers Computer Aided Cost Estimating System (CACES), the Control Estimate Generator (CEG), the results of a survey done by Purdue University, and related work done at the Massachusetts Institute of Technology (MIT) were used to determine the critical factors and milestones in construction activity. CACES/CEG generated data was applied to an Army barracks building to provide initial activity durations.

Scope

This study served as a foundation for developing a contract duration estimating system.[2] The activities and logic of the generic schedule discussed in this research are based on a three story barracks building built in Southern California. Required inputs to the system are overall project parameters and specific activity information and durations. Factors applied to individual activities provided in this report serve as a foundation, not as an exhaustive list, of the ways in which project and activity data impact the overall completion of projects.

Mode of Technology Transfer

It is anticipated that the information and processes derived in this part of the study will be incorporated into an automated construction duration estimating system (CODES), which will be fielded throughout the Corps of Engineers through Huntsville Division courses.

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[2] Ruofei Sun, Guruprasad N. Rao, Diego Echeverry, and Simon Kim, *A Prototype Construction Estimating System (CODES) for Mid-Rise Building Construction*, Interim Report (IR) P-91/43/ADA240003 (U.S. Army Construction Engineering Research Laboratory [USACERL], July 1991).

2 FACTORS AFFECTING ACTIVITY DURATIONS

Introduction

This chapter describes how activity completion time may be affected by project or activity characteristics. Once these characteristics, or factors, are identified, then the factors may be applied to the activities in a generic schedule to produce an overall contract duration.

The first five sections of this chapter describe existing automated systems, completed research, and knowledge elicitation efforts that have identified project and activity characteristics that affect overall project completion.

The first section of the chapter introduces the parameters used by a Corps of Engineers conceptual cost estimating system. The second section provides a synopsis of the results of a survey conducted at Purdue University to determine the critical factors and milestones in contract durations. The third section briefly describes related work at the Massachusetts Institute of Technology (MIT). The fourth section of the chapter discusses the contractor interviews that were conducted to identify schedule constraints. The fifth section of the chapter describes several of the constraints developed through project team meetings.

In the following section of this chapter, the authors generalize the types of characteristics, or factors, that impact activity durations and the logic between activities. The breakdown of a generic schedule is discussed in a following section of this chapter (p 24). Finally, a matrix is provided that displays the factors which are relevant to each activity in the schedule (p 55).

Control Estimate Generator

The use of a conceptual cost estimating system requires the estimator to input parameters needed to identify major cost components of fixed facility types. These facility types are described by fixed building systems, the cost of which change depending on the parameters.

One such system is the Control Estimate Generator (CEG) developed by the U.S. Army Corps of Engineers. The CEG system, when combined with the microcomputer version of the Computer Aided Cost Estimating System (CACES), called Composer, provides facility planners and architects with an initial breakdown of labor, material, and equipment costs based on a small set of parameters for 44 fixed facility types.

Labor cost estimates of the CEG are calculated using simplified default crews and labor hours based upon gross building dimensions. Material and equipment costs are similarly calculated based on default materials and equipment requirements for the gross building dimensions or characteristics. Complete initial estimates from the CEG system provide a detailed cost breakdown.

There are four mandatory and 14 optional items that the estimator needs to input to the CEG system.[3] Table 1 lists these parameters. While the 44 building types in the CEG are fixed, the 18 CEG parameters fall into two general categories.

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[3] Estimate File Builder Facility Parameters were taken from Computer Aided Cost Estimating System (CACES)—Control Estimate Generator (CEG) User's Manual, CEHNDSP 88-219 (U.S. Army Corps of Engineers, Huntsville Division, 30 September 1988), p 5-5.

Table 1

CEG Parameters

Mandatory Items	Optional Items
• Gross floor area	• Footprint area at grade
• Facility type	• Facility perimeter length
• Heating energy source	• Stories above grade
• Cooling energy source	• Floor-to-floor height above grade
	• Stories below grade
	• Floor-to-floor height below grade
	• Piling depth
	• Number of stairwells
	• Average ceiling height
	• Percent full height partitions
	• Plumbing fixtures
	• Heating BTU
	• Cooling BTU
	• Sitework

The first category of parameters is used to size the default building systems. The user provides gross dimensions for the facility to be estimated. In the second category, parameters are used to differentiate between different types of functionally similar building systems. For example, "Heating Energy Source" is used to differentiate between gas and oil fired heating.

There are three characteristics of the CEG/CACES system that make output from the system difficult for use in scheduling. The first of these is that the CEG/CACES system is based on a cost-oriented breakdown used for estimating, not on a task or activity breakdown. The second difficulty is that the breakdown provided is extremely detailed and cannot be easily grouped into activities. Finally, the crews provided by CEG/CACES are fixed crews for every item in the breakdown. These crews can not be easily aggregated into typical construction crews.

Survey of Scheduling Parameters

A recent study conducted by Purdue University surveyed over 50 different contractors to ask contractors which factors most affected a project's completion date.[4] The contractors were also asked which project milestones were most critical for project completion.

After this data was compiled, two regression models were developed. The first model attempted to predict overall project completion. The second model attempted to predict completion of individual project milestones.

This survey provides some insight into elements to consider when determining activity or project durations. The Purdue study also provides evidence that statistical regression models of contract or milestone completion do not provide accurate results.

Table 2 shows a ranking of project factors, as presented by the Purdue study, that contractors indicated had the most impact on project completion. Table 3 shows the ranking of project milestones that were thought to be critical by contractors, in this study.

[4] Joseph Orczyk, *Parametric Construction Scheduling*, PhD Thesis (Purdue University, May 1989).

Table 2

Purdue Ranking of Project Factors

Number	Factor
1	Type of structural frame
2	Owner's schedule
3	Subsurface conditions
4	Type of exterior cladding
5	Number of floors
6	Month construction begins
7	Availability of labor
8	Type of foundation
9	Volume of cut/fill
10	Total floor area
11	Quality of labor
12	Location, city
13	Supported floor area
14	Exterior wall area
15	length of parameter
16	Story height
17	Shape of floor plan
18	General quality of building
19	Type of HVAC
20	Building volume
21	Finished floor area
22	Labor: union/non-union
23	Floor area on grade
24	Total site area
25	HVAC requirements, tons
26	Building code class
27	Roof area
28	Type of construction contract
29	Length of partitions
30	Connected power load
31	Type of roofing
32	Presence of sprinklers
33	Area of paving
34	Type of doors
35	Type of interior partitions
36	Area of landscaping
37	Number of occupants
38	Type of ceiling finish
39	R-value of exterior wall
40	Type of interior wall finish
41	Type of floor finish
42	Type of insulation
43	Fire detectors required

Table 3

Purdue Ranking of Project Milestones

Rank	Milestone
1	Certificate of substantial completion
2	Completion of frame erection
3	Completion of elevator
4	Completion of exterior cladding
5	Start frame erection
6	Complete electrical
7	Complete pouring foundation
8	Start exterior cladding
9	Notice to proceed
10	Complete plumbing
11	Start forming foundation
12	Complete glazing
13	Complete HVAC test/balance
14	Start elevator
15	Complete interior finishes
16	Complete roofing
17	Complete concrete topping
18	Complete punchlist items
19	Start glazing
20	Start HVAC
21	Start above ground electrical
22	Start roofing
23	Complete under ground utilities
24	Start above ground plumbing
25	Complete interior partitions
26	Complete door hardware
27	Start HVAC test/balance
28	Start interior partitions
29	Complete walks/drives
30	Start door hardware
31	Complete lanscaping
32	Start walks/drives

Analysis of Construction Project Risks

MIT researchers developed a framework for analyzing construction project risks.[5] This framework was designed to allow project managers to interact with project data and to evaluate the impact of various types of risk on a project. While the report primarily focuses on causes of problems that occur

[5] Leston B. Nay and Robert D. Logcher, *An Expert Systems Framework for Analyzing Construction Project Risk*, MIT Center for Construction Research and Education Report No. CCRE85-2 (Massachussetts Institute of Technology [MIT], February 1985).

after a project has begun, the results are also applicable to this study. Several of the concepts presented in this report are risk factors and selection rules that may affect duration.

In this MIT project, risk factors are types of constraints that may cause a deviation from expected project performance. The selection rules, based on general project information, determine which risk factors should be applied to specified types of work. The report defines a risk occurrence as "a set of events or conditions which taken together are capable of causing work package performance measures to deviate undesirable from expectations."[6] Since one type of performance "measure" is construction duration, this definition implies that there is some set of factors that, based upon project conditions, may change a project's duration.

This research provides a foundation for the concept of using activity or project factors to impact activity completion. The impact of changes, or "risk occurrence," to an activity will occur only after some criteria, or "selection rules" have been satisfied. This type of organization indicates that IF-THEN rules may be used to evaluate if changes to an activity will take place.

The next two sections of this chapter show how this concept of applying factors based on activity or project parameters may be applied to change activities' original durations and originally scheduled start and completion dates.

Contractor Interviews

Several interviews were conducted with contractors operating in the Midwestern area of the United States. The purpose of these interviews was to attempt to identify activity or project factors that would impact activities' original durations or originally scheduled start and completion dates. The interviews allowed the contractor's personnel to speak freely about topics that impacted schedules. As the contractor personnel discussed a topic, the interviewers were able to extract more specific project planning knowledge.

Information gleaned through these interviews was typically in a very high level form such as "You can't start steel construction until procurement has been completed. Procurement can take up to 16 weeks." From this type of information, common types of factors such as "procurement-delay" that applied to a number of activities were identified.

Figure 1 shows an example of the procurement delay factor. An initial schedule may show that the early start of an activity could occur 90 days after the project start date. If, however, the activity requires a minimum number of days for procurement, 120 days for example, then the activity's early start date must be delayed until 120 days after the project start date. Typical contractors' schedules do not include this type of data because contractors tend to be optimistic and because the data is not always specifically known. The inclusion of this type of specifically unknown but generally estimated information potentially provides, therefore, a more realistic schedule.

Project Team Interaction

From the contractor interviews, the development team was able to identify three categories of factors that could cause unexpected delays: work delays, weather delays, and productivity delays.

An example of the work delay factor is construction material breakage. Typically, activities delayed by breakage are those that require the installation of unusually shaped or fragile materials. For example,

[6] Nay, p 79.

exterior closure systems such as glass curtain walls or specialized precast systems are susceptible to delays due to material breakage during handling and installation.

Figure 2 illustrates the work delay factor. The initially estimated duration of an activity that is susceptible to delay may be 50 days. However, due to the potential delay this duration may actually be 10 percent short. After extending the activity by 10 percent, to the activity, the revised duration would be 55 days. This revised duration should be used in schedule calculation to provide a more accurate estimate of project duration. Some other possible work delays are: poor subsurface conditions and building in remote locations.

The second category of activity delay identified during these meetings was weather delays. In bad weather, workers cannot always complete a task. Rather than work with low productivity, contractors prefer to delay the start of an activity until sufficient productivity can be maintained.

Figure 3 shows the result of weather delays on activity scheduling. The top bar of Figure 3 illustrates a simplified view of a weather-sensitive activity scheduled during poor weather. The actual duration of the activity is shown by two parts. The first part is the originally estimated activity duration. The second part of the actual activity duration is the estimated weather delay. The activity's actual duration, in the top bar, is twice the originally estimated duration.

To more realistically schedule the activity in Figure 3, the start of the activity would be delayed until an acceptable weather delay is achieved. This process may take several iterations. For example, the middle bar of Figure 3 shows a 30 percent extension of the estimated duration required for an actual duration. If this is not an acceptable level of delay due to weather, then the start of the activity would be pushed back again.

The final start date of an activity, shown as the bottom bar in Figure 3, would be determined when additional weather delay reaches an acceptable level. The duration used to calculate the schedules early completion date is then based upon the originally estimated duration plus the acceptable level of weather delay.

The final category of factors identified by the development team were called productivity delays. Productivity delays are caused by sequences of activities with different durations over the same work area. An example of the interaction between activities' duration and work area is shown in Figure 4. This type of scheduling is referred to as a "split" schedule.

The top activity in Figure 4 shows an activity composed of repetitive work through three work areas. Following this first activity is another activity that has a shorter duration. If each portion of the second activity were to be scheduled as soon as possible, then the crew for the second activity would have to mobilize and remobilize several times. Typically, the second crew would simply reduce productivity to slow work progress to fill the time available.

A contractor would like to minimize either a "multiple mobilization" or a "reduced productivity" scenario. This is accomplished as shown in Figure 5. In Figure 5, the second activity is delayed until sufficient work exists to allow the second crew to productively complete the work. The crew may arrive on the site, work from the start to the end of the task and then move on to the next job. This type of schedule is referred to as a "non-split" schedule.

Figure 6 illustrates the two different types of logical connections between activities used in this project. The top portion of Figure 6 illustrates a situation in which a non-split sequence is used. The start-to-start and finish-to-finish logic sequence may have durations associated with them. The "lead" is the duration of the start-to-start connection. The "lag" is the duration of the finish-to-finish connection. The bottom portion of Figure 6 illustrates when a traditional finish-to-start may be used to simplify the schedule.

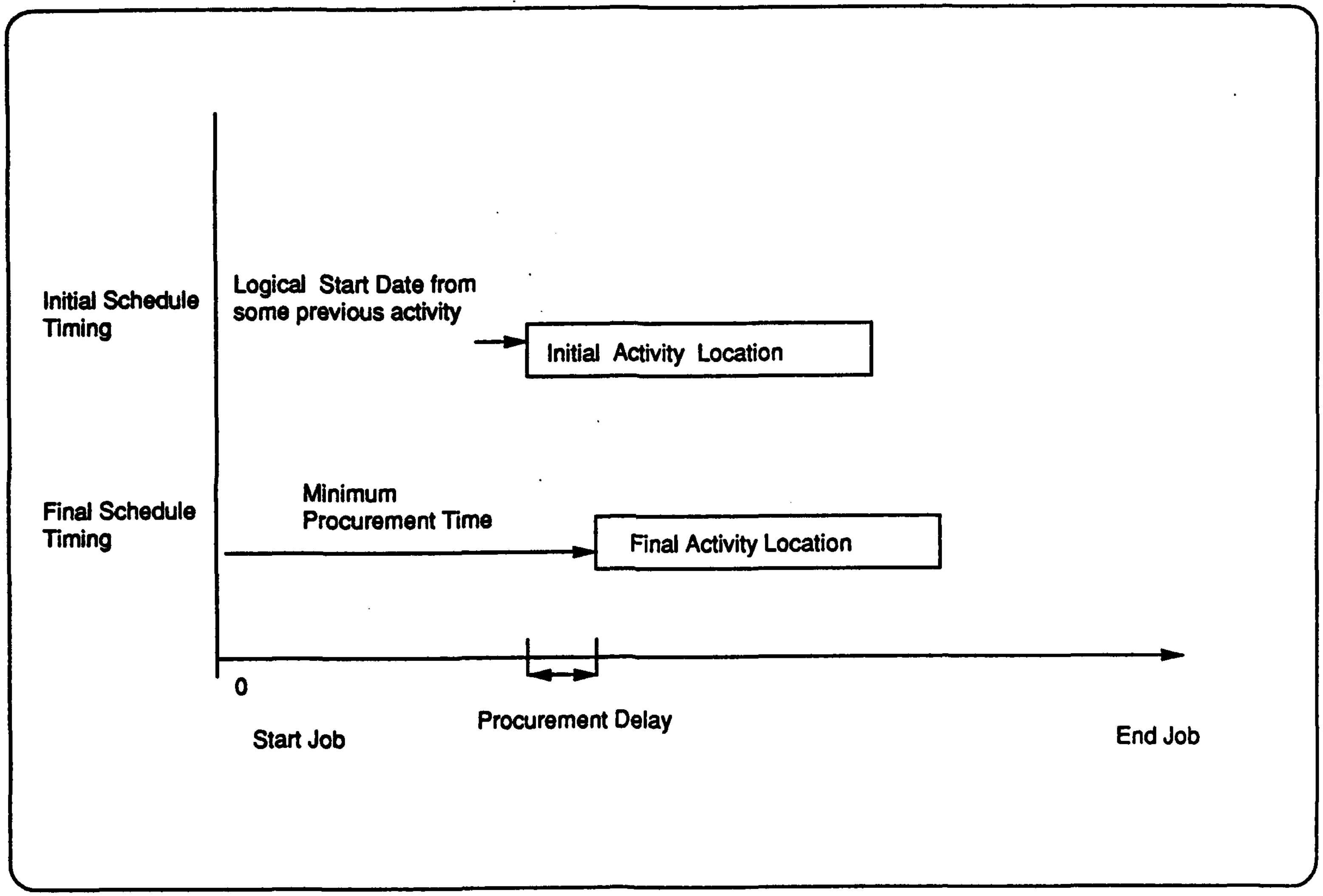


Figure 1. Impact of Procurement Delays.

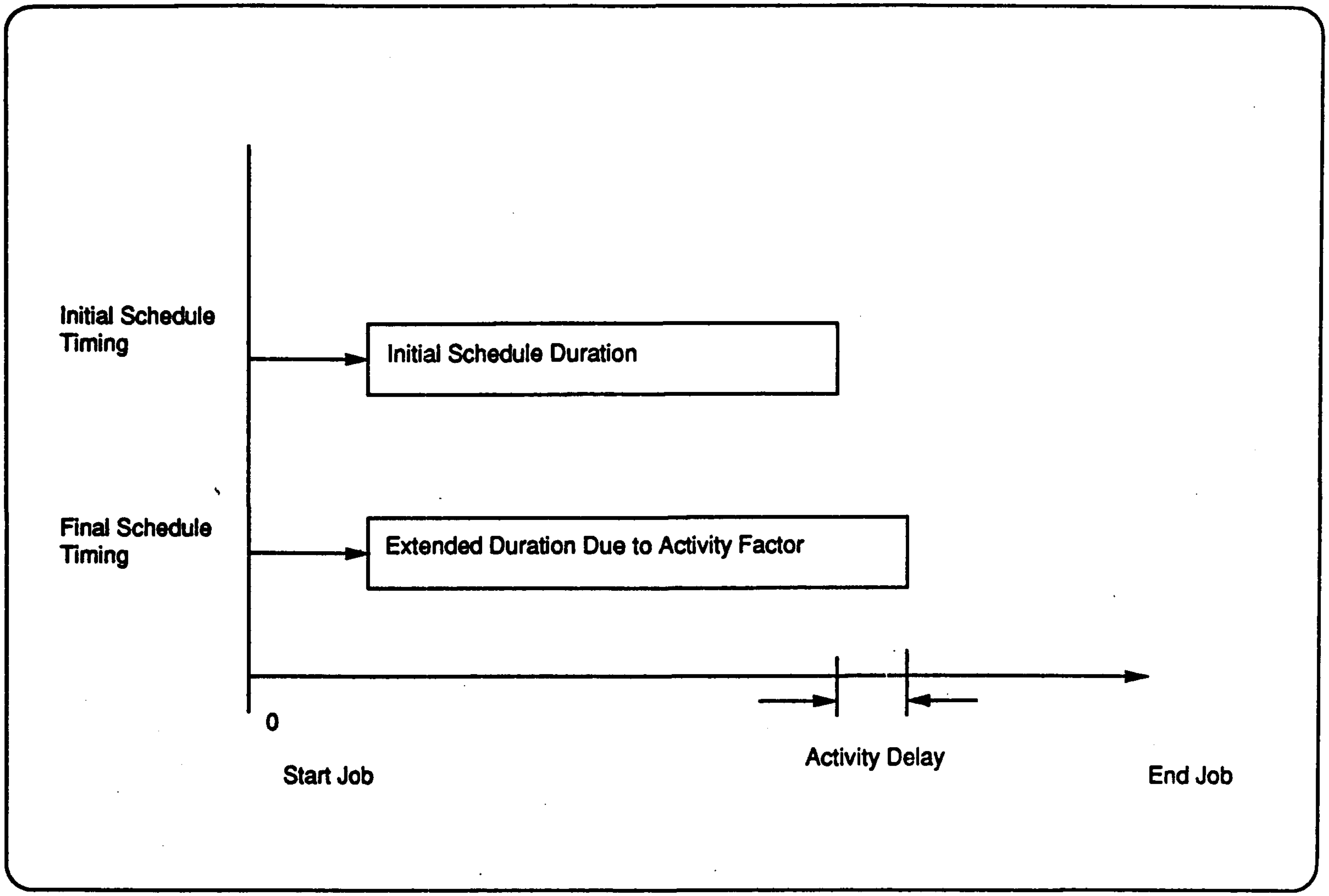


Figure 2. Impact of Work Delays.

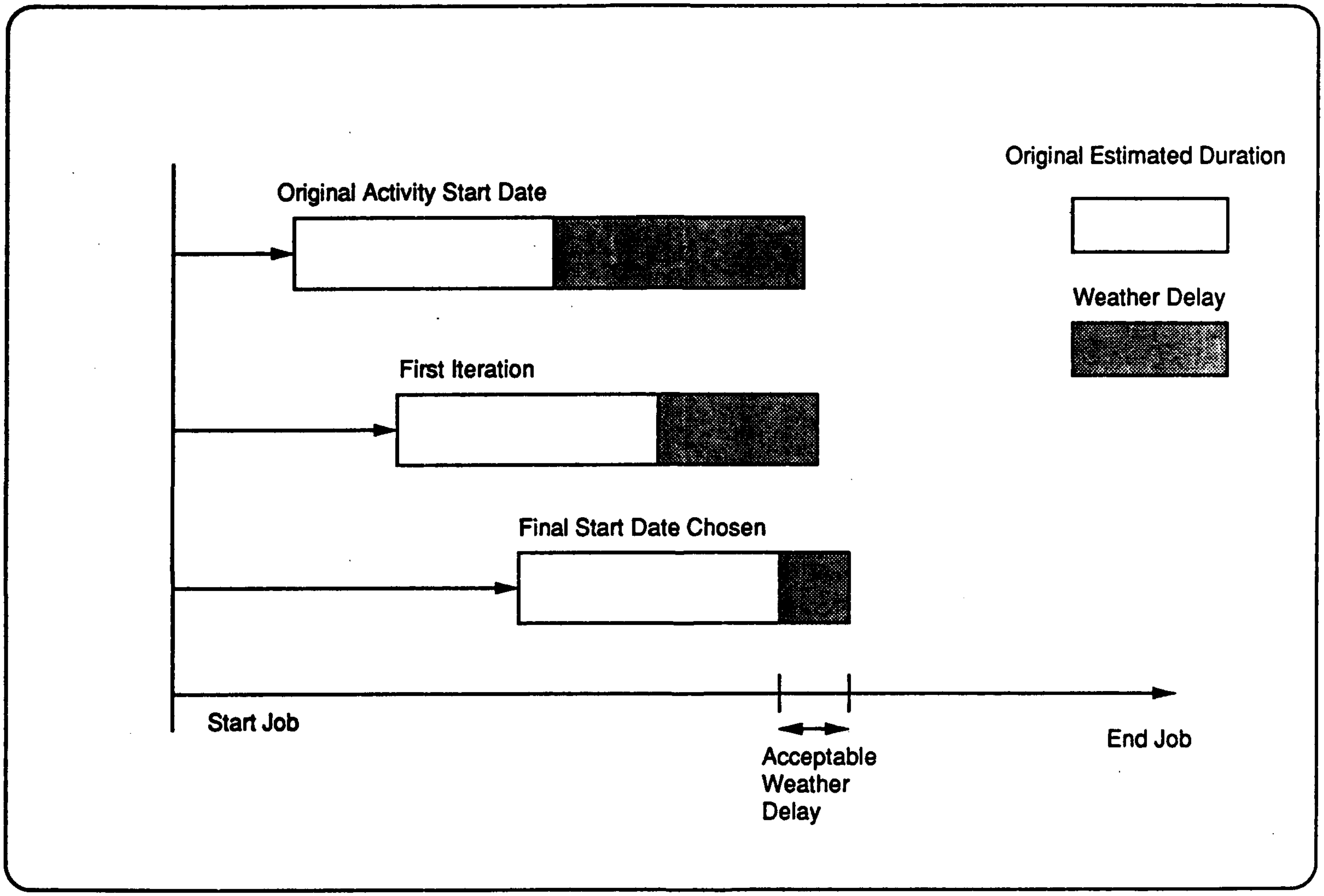


Figure 3. Impact of Weather Delays.

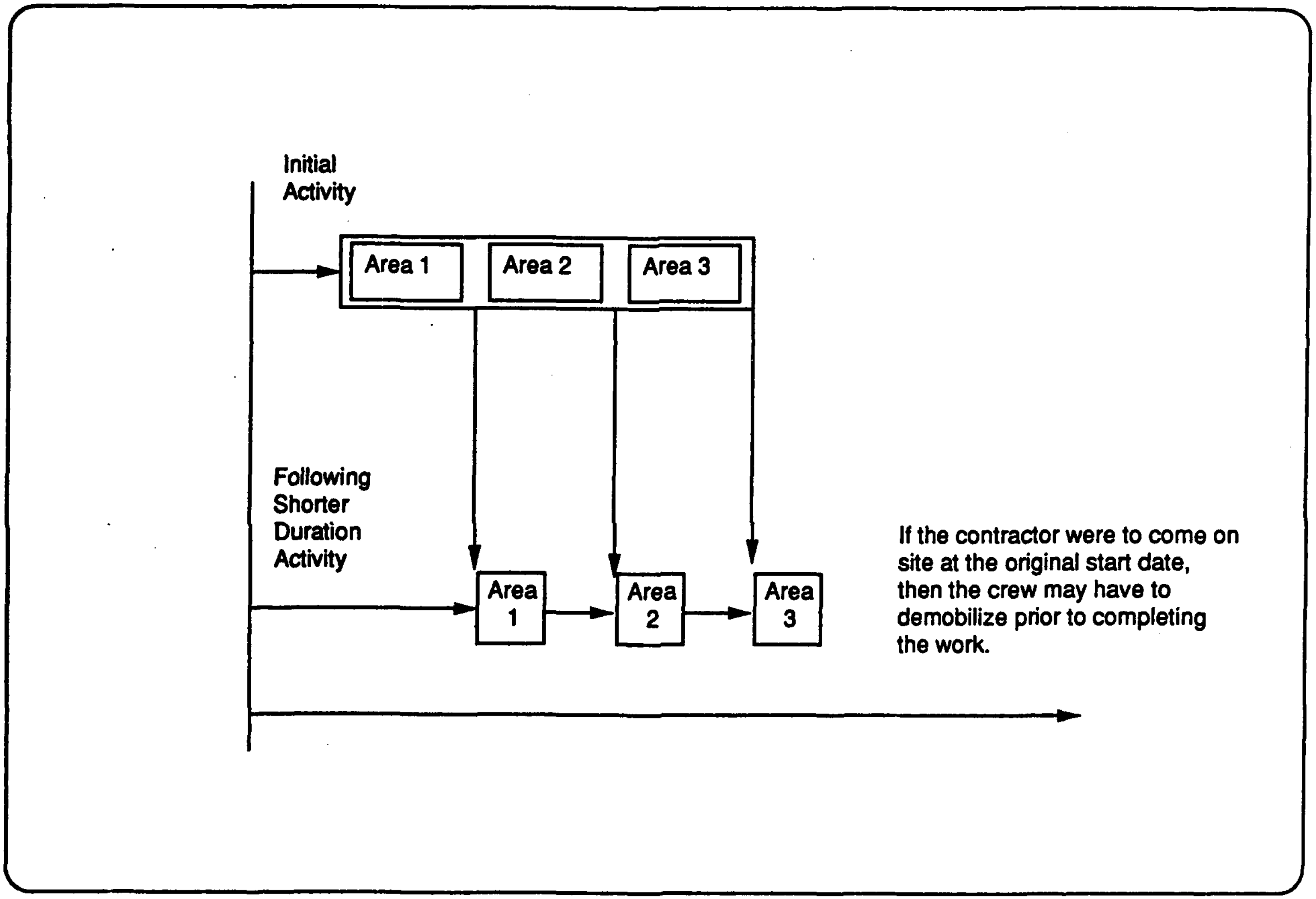


Figure 4. Impact of Durations on Productivity.

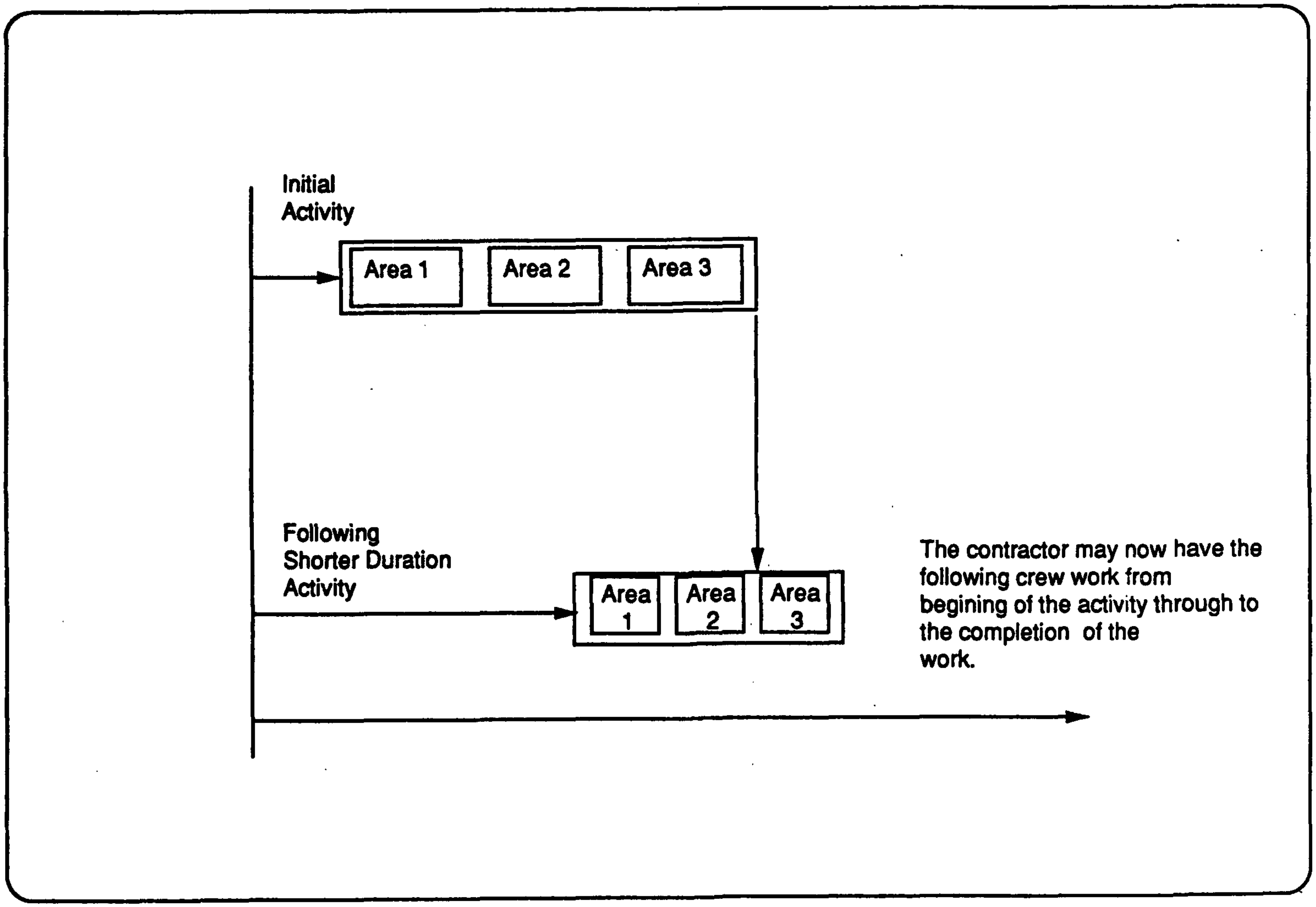


Figure 5. Creating the Non-Split Solution.

The logic between activities is directly affected by project characteristics. For example, the relationship between foundation and structure is different on a large single story warehouse from that on a 50-story office building. On a large single story warehouse, the structure will typically be started after the shallow foundation has begun and will follow the foundation work across the facility. On the office building, however, deep foundations are usually completed before starting any structural work, because both activities require heavy equipment to work in the same limited space. In many cases, the type of building systems to be built imply some specific sequencing.

Formalizing Factor Categories

Preliminary study showed that specific factors are associated with specific types of construction work. Further, these factors also appear to have well defined formats. This section identifies the categories of factors identified and defines a consistent format to represent them.

To impact an activity, a factor will normally have some type of threshold. If the threshold is exceeded, then the factor should be applied to the activity. Most factors are of the following format: "IF the threshold value is exceeded, THEN apply the factor." This rule-type format will be the basis of defining a consistent representation of activity factors and their impacts.

Factors may affect both the timing of activities and the logical connections between activities. Those factors that impact timing may change the originally estimated start or finish dates, or duration of a given activity. Factors affecting logic between activities specify both the type of logic, concurrent or sequential, and lead and lag times.

Procurement Delay Factor

Activities typically start based on their relation to preceding activities. Some activities, however, have special start date constraints associated with them. These delayed start dates may be due to potential procurement delays. The generalized format for procurement delays is as follows:

IF

the activity has a potential of procurement delay,

THEN

delay the start of the activity by the typical procurement period for this type of activity.

The above formalization of the procurement delay factor is not really as deterministic as it may seem. Although it may be easy to identify those activities that have the potential of procurement delays, determining the typical procurement delay for all projects may not be possible.

Determining the typical procurement period will be highly dependent on many items, which could not all be included in any system. The items impacting typical procurement time include: location of site, financial stability of contractor and subcontractors, and priority procurement status. General economic factors also impact procurement delays. Examples of some general economic factors are: amount of production capacity available versus amount of product required, status of factory production runs, relation between suppliers and contractors, etc.

While the formalization of the procurement delay factor is not deterministic, the process of writing the rules allows the system to capture generalizations about scheduling. One example of such a generalization is: "steel activities cannot start until after procurement." The benefit of these rules is that

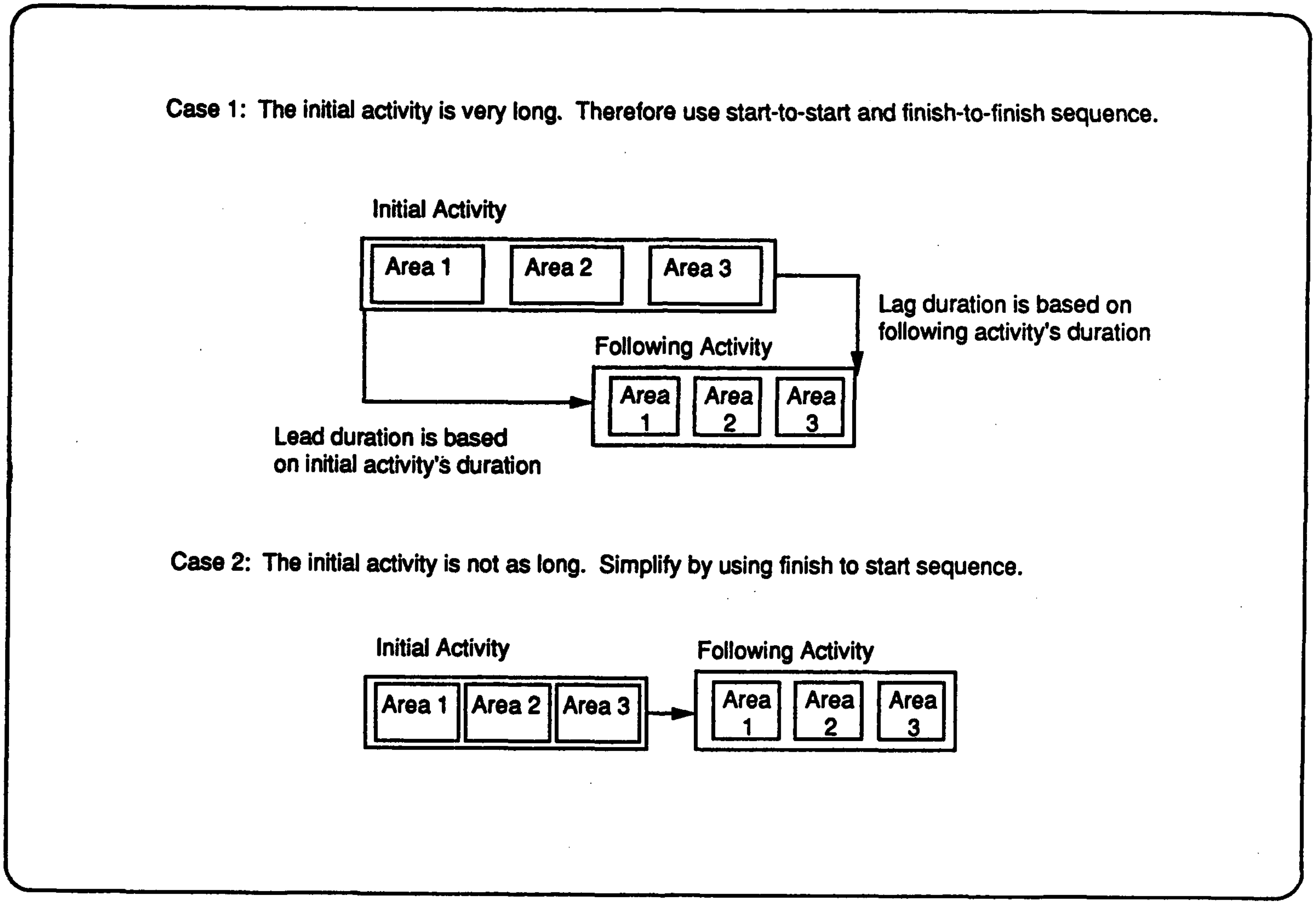


Figure 6. Implementing the Non-Split Solution.

they allow the system to interact intelligently with the user. If the procurement delay is unknown, then the user may be queried. If the typical procurement delay has been previously provided, then the system may use it to estimate the duration of the procurement delay.

Given the appropriate interface, using a rule type format to contain activity information allows users in different locations to customize rules for their specific projects. While these rules may not cover all possible construction projects, or provide correct estimates for every possible project, they can provide the architecture for a system that may intelligently assist project managers to create schedules.

Work Delay Factor

Work delay factors allow modification to an activity's originally estimated duration. As in the procurement delay factor illustrated above, the work delay factor has a rule with two parts, an antecedent and a consequent. The work delay rule's antecedent, or "left-hand side," looks for some condition related to the activity, for example: poor subsurface conditions, remote locations, or sensitivity to breakage. If the activity has this characteristic, then the consequent is activated. The consequent for the work delay rule increases the original duration of the activity by some predetermined percentage. For example, if the activity was "sensitive to breakage," then the duration of the activity may be increased by 10 percent over its originally estimated duration.

The generalized form of the work delay factor is shown below. The "X" represents the characteristic of an activity that triggers a delay. The "Y" represents the percent time extension that an activity will experience if the condition "X" is present. In the previously mentioned example, "sensitive to breakage" would be substituted for "X" and "10 percent" would be substituted for "Y".

IF
    the activity has characteristic X,
THEN
    increase the duration of the activity by Y percent.

Weather Delay Factor

Weather impact on construction is well known, but often overlooked in developing conceptual schedules since the sequence of construction may not be known during the conceptual design phase. Using the weather delay factor rule, shown below, the impact of weather may be identified prior to starting the project. The "X percent" is the percentage an activity is delayed due to weather. The "Y percent" is the maximum acceptable weather delay.

IF
    the activity is delayed by X percent due to weather,
THEN
    delay the start of the activity until the weather delay is less than Y percent of the duration.

This rule represents a somewhat different type of rule, called an iterative rule. Although the use of iterative procedures is widely understood and used, the following explanation is provided for completeness. The iterative weather delay rule states: (1) find the weather delay associated with a particular activity, (2) if the weather delay is greater than the maximum acceptable weather delay, then (3) delay the start of the activity, and (4) repeat the procedure until the delay is less than the maximum acceptable weather delay. By using iterative rules, the system can delay scheduling weather-sensitive construction until the contractor can achieve an acceptable level of delay caused by weather.

Productivity Delay Factor

The productivity delay factor allows the project planner to better understand the probable work flow of the contractor. Figures 4 and 5 illustrate the interaction between two activities as the project progresses through multiple work areas. Figure 4 shows the typical scheduling pattern provided by the CPM algorithm. Notice that the following activity in Figure 4 is split into three separate parts. Figure 5 shows the typical scheduling pattern which a contractor would like to follow. The second activity in Figure 5 illustrates a non-split schedule.

Contractors generally prefer to follow a non-split schedule since this increases productivity. This increase in productivity is due to a decrease in mobilization costs and time, and the impact of the "learning curve." The following rule illustrates the productivity delay factor:

IF

an activity is originally scheduled in a split configuration,

THEN

delay the start of the activity until the activity can be scheduled in a non-split fashion.

Both the weather and productivity delay factors are somewhat unique compared to the many types of work delay factors. Work delay factors are applied directly to an activity's originally estimated duration. Weather and productivity factors cannot be applied until the initial timing and sequence of the activity is known.

Conditional Sequence Factor

This factor changes the sequence of two activities based on some criteria related to the characteristics of the work to be accomplished in the project. For example, if there are no underground stories in the building that need to be excavated, then site utilities may be constructed concurrently with site preparation. On the other hand, if there are several underground stories, then site utilities may be delayed until after most of the site preparation has been completed since site access will be limited.

Three rules for each activity are used to model conditional logic. The first of the three rules covers the simple case in which there is a conventional finish-to-start relationship between the activities. The next two rules establish a start-to-start and finish-to-finish sequence between the activities. The selection of either the finish-to-start or start-to-start and finish-to-finish sequence is based upon the criteria established in the rule.

The three rule formats required to model the conditional logic are shown below. The constraints used in these rules attempt to identify the number of work areas in a building. For example, the interior construction may concurrently follow the steel structure if there are more than three floors. If the structure has fewer than three floors, then the contractor does not start interior construction until after the completion of the structural steel. These logical rules allow the system to store practical scheduling rules of thumb about how to sequence the project.

RULE 1 (traditional finish-to-start logic):

If some constraint is satisfied, then set the start of the next activity equal to the finish of the current activity.

RULE 2 (start-to-start logic):

If some constraint is satisfied, then set the start date of the next activity equal to the start date of the current activity, and set the lead of the next activity equal to some percentage of the current activity.

RULE 3 (finish-to-finish logic):

If some constraint is satisfied, then set the finish date of the next activity equal to the finish date of the current activity, and set the lead of the next activity equal to some percentage of the next activity.

The use of percentages may be supplemented in more robust implementations through the direct application of building work area factors. The approach used here emphasizes a simplicity for purposes of presentation. The examples used later in this report also contain percentages used to illustrate a possible system architecture, and not a defined knowledge base.

Summary of Formalized Factors

Table 4 summarizes the formalized factors identified by contractor interviews and development team interaction in this section of the Chapter.

Schedule Activities and Sequence

To apply the preceding discussion of factors to develop an overall project duration, each factor needs to be associated with specific activities. In addition to the activities and factors, the sequence in which the activities occur in a project will be needed to calculate the completion date of a project. This section of the chapter introduces the selected activity set, and the sequence between activities.

Table 5 provides an example of generic activities based on a steel-framed barracks building. As noted previously, the type of building systems contained in a project will directly impact the schedule. Therefore, other types of projects may have more or fewer activities and a different sequence than this steel-framed structure.

This breakdown was chosen to assist in evaluating the application of CACES/CEG estimating data to duration estimating. Since the CACES/CEG system is also based upon the BSI coding scheme, it was hoped that a direct translation between the CACES/CEG system and the activities used in this study could be achieved.

A direct correlation, however, could not be achieved under the present configuration of the CACES/CEG system. An example of the difficulty in translating the CACES/CEG system is shown in the "Mechanical and Electrical Rough-In and Finish" activities (activities 10, 11, 15, and 16). There is no distinction in the CACES/CEG system between Rough-In and Finish work but this separation is essential in schedule generation to define a proper sequence of construction.

Once the activities have been determined, the sequence between the activities was defined. The basic assumption of this research project is that there are some essential qualities of planning construction work that are common to many different projects. These common qualities include both the sequence of work and the various factors associated with specific activities.

Table 4

Formalized Factor Summary

Procurement delay factor
Duration delay factors (poor site conditions, breakage, remote location, etc.)
Weather delay factor
Productivity factor
Conditional sequence factor

From the preceding assumption, it may be concluded that it is possible to model the schedules of several different projects by the same network logic and factors.* Based on this assumption, the research team strived to determine an efficient way to group projects together.

Initial efforts focused on the way that the Corps of Engineers, CEG system categorized projects. The 44 categories of projects in the CEG system were developed based on the functional use of the completed facility. For example, "Barracks" is a typical classification of building category. Any given category may include many different types of structural and closure systems.

Attempts to produce generic schedules for given building functions proved, however, to be inappropriate. A single schedule developed around a specific building type must contain a large number of activity factors and sequence rules to cover all possible building systems that could be used in the facility. As a result, the CEG facility type schedules were abandoned in favor of templates organized around structural systems.

Interaction of Factors and Activities

Table 6, the Activity-Factor Matrix shows how specific factors identified in Chapter 2 are applied to each activity. Along the top of each page of the table are the list of activities from Table 4. On the left side of the matrix are the factors identified in Chapter 2. The first set of factors (numbered 1 through 43) are the factors from the Purdue study. These factors were previously noted in Table 2. The next set of factors (numbered 44 through 61) are the parametric estimating data elements required for the CEG system. The CEG parameters were previously listed in Table 1. Finally, the factors developed through the analysis of contractor interviews and team meetings (numbered 62 through 66) are provided.

Table 6 shows which factors have been specifically applied in later sections of the report as examples of how the factor rules are applied to specific activities. This table also shows which factors may impact an activity but were not applied in the example applications that follow. The dark filled check marks illustrate those factors that have been applied. The open check marks illustrate those factors that may impact but were not considered significant for the example application.

* Throughout the remainder of the report, the phrases "generic" or "template" schedule will refer to a archetypical schedule that represents more than one project.

Table 5

Conceptual Activity List

Number	Description
1	Start job
2	Site preparation
3	Site utilities
4	Foundation
5	Structure
6	Roofing
7	Exterior
8	Equipment
9	Interior construction
10	Mechanical rough-in
11	Electrical rough-in
12	Interior finish
13	Site improvements
14	Specialties/furnishings
15	Mechanical finish
16	Electrical finish
17	End job

Generic Activity Examples

This section provides examples of how the factors were applied to individual activities in a generic project. The first part of this format is the identification that the activity is a member of the generic activity network. This item was included for reference and completeness. The second part is the activity number and description.

The third part of the description lists the factor rules applied to the activity for the purposes of this project. These rules refer to Table 6, the Activity-Factor Matrix, as filled check marks. The fourth part provides the different possible logical relationships between the activity and other activities. This section lists the rules necessary to determine the sequence, or logic, for the activities.

The rules in the third and fourth parts of the activity descriptions have been numbered for ease of reference. In addition, each rule includes a citation of the source for the rule. These sources refer to specific activity factors shown in Table 6, contractor interviews, and team meetings.

The fifth part shows the factors that may affect the activity but were not applied in this study. These factors refer to Table 6, the Activity-Factor Matrix, as open check marks. Finally, the components of the activity, based upon the BSI designation are provided. The BSI breakdown is also used by the CACES/CEG system. The activity components are provided to allow future exploration of coordinating CACES/CEG data with this system.

Following the individual activity descriptions, there is a network diagram for the generic network (Figure 7). The reader is encouraged to refer to this diagram while reviewing the activity descriptions.

Table 6

Activity-Factor Matrix

Activity → / Activity Factor ↓	17 End Job	16 Elec. Fin	15 Mech. Finish	14 Special/Furnish	13 Site Improvement	12 Interior Finish	11 Elec. Rough-in	10 Mech. Rough-in	9 Interior Const.	8 Equipment	7 Exterior Closure	6 Roofing	5 Structure	4 Foundation	3 Site Utilities	2 Site Preparation	1 Start Job
1 Type of Structure					✓		✓	✓	✓		✓		✓	✓	✓	✓	
2 Owner's Schedule	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3 Subsurface Conditions														✓		✓	
4 Type of Exterior Cladding						✓					✓		✓				
5 Number of Floors				✓					✓		✓	✓	✓				
6 Month Const. Begins											✓	✓	✓	✓	✓	✓	✓
7 Availability of Labor		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8 Type of Foundation														✓			
9 Volume Cut/Fill					✓										✓	✓	
10 Total Floor Area		✓	✓	✓		✓	✓	✓	✓				✓	✓		✓	
11 Quality of Labor		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12 Location, City				✓									✓		✓		
13 Supported Floor Area													✓	✓	✓		
14 Exterior Wall Area											✓						
15 Length of Perimeter														✓	✓	✓	
16 Story Height						✓			✓				✓				
17 Shape of Floor Plan		✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	
18 General Quality		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
19 Type of HVAC			✓			✓	✓	✓		✓					✓		
20 Building Volume													✓				
21 Finished Floor Area				✓		✓											
22 Labor Union/Non-Union		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
23 Floor Area at Grade														✓	✓	✓	

Table 6 (Cont'd)

Activity Factor ↓ / Activity →	17 End Job	16 Elec. Fin	15 Mech. Finish	14 Special/Furnish	13 Site Improvement	12 Interior Finish	11 Elec. Rough-in	10 Mech. Rough-in	9 Interior Const.	8 Equipment	7 Exterior Closure	6 Roofing	5 Structure	4 Foundation	3 Site Utilities	2 Site Preparation	1 Start Job
24 Total Site Area					✓									✓	✓	✓	
25 HVAC Requirements			✓				✓	✓									
26 Building Code Class		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
27 Roof Area												✓					
28 Type of Contract		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
29 Length of Partitions						✓			✓								
30 Connected Power Load		✓					✓								✓		
31 Type of Roofing												✓					
32 Presence of Sprinklers			✓			✓		✓	✓								
33 Area of Paving					✓												
34 Type of Doors						✓			✓								
35 Type of Int. Partitions		✓	✓	✓		✓	✓	✓	✓								
36 Area of Landscaping					✓												
37 Number of Occupants									✓								
38 Type of Ceiling Finish		✓	✓			✓											
39 R-Value of Ext. Walls											✓	✓					
40 Type of Int. Wall Finish		✓	✓	✓		✓											
41 Type of Floor Finish				✓		✓											
42 Type of Insulation											✓	✓					
43 Fire Detectors Required		✓	✓				✓	✓									
44 Gross Floor Area																	
45 Facility Type		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
46 Heating Energy Source		✓	✓			✓	✓	✓							✓		

Table 6 (Cont'd)

Activity Factor ↓ / Activity →	17 End Job	16 Elec. Fin	15 Mech. Finish	14 Special/Furnish	13 Site Improvement	12 Interior Finish	11 Elec. Rough-in	10 Mech. Rough-in	9 Interior Const.	8 Equipment	7 Exterior Closure	6 Roofing	5 Structure	4 Foundation	3 Site Utilities	2 Site Preparation	1 Start Job
47 Cooling Energy Source			✓			✓	✓	✓							✓		
48 Footprint at Grade														✓	✓	✓	
49 Perimeter Length														✓	✓	✓	
50 Stories Above Grade									✓	✓	✓	✓	✓	✓			
51 Flr-Flr Height Abv. Grade						✓	✓	✓					✓				
52 Stories Below Grade									✓	✓			✓	✓	✓	✓	
53 Flr-Flr Height Bel. Grade						✓	✓	✓					✓	✓	✓	✓	
54 Piling Depth														✓			
55 Number of Stairwells						✓			✓				✓				
56 Average Ceiling Height						✓	✓	✓	✓								
57 Percent Full Partitions		✓	✓			✓		✓	✓								
58 Plumbing Fixtures			✓					✓									
59 Heating BTU		✓	✓				✓	✓									
60 Cooling BTU		✓	✓				✓	✓									
61 Sitework					✓										✓	✓	
62 Mobilization Time																	✓
63 Procurement Time				✓			✓	✓		✓			✓				
64 Weather					✓						✓	✓	✓	✓	✓	✓	
65 Productivity		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
66 Breakage		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓		

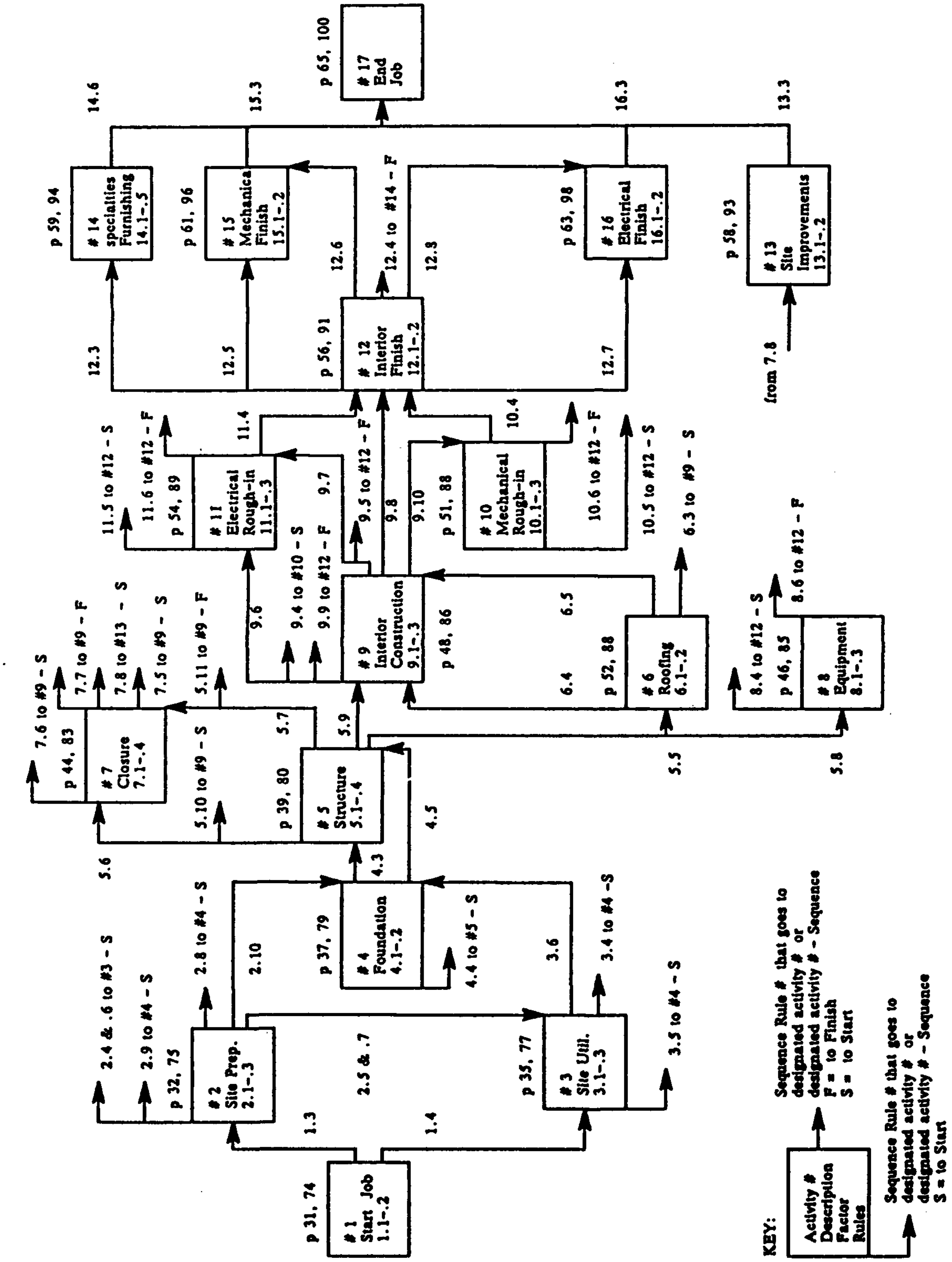


Figure 7. Conditional Steel-Framed Network.

Activity 1—Start Job

Factor Rules Applied:

1.1 The early start of the schedule is equal to the project's contract starting date.

Source: Activity factor 6, "month construction begins."

1.2 The duration of this activity is equal to the time required for the contractors to mobilize their forces. A default of 15 days will be used.

Source: Activity factor 62, "mobilization time"; contractor interviews.

Sequence Rules:

1.3 Finish-to-start with Activity 2, "Site Preparation."

Source: Contractor interviews/team meetings.

1.4 Finish-to-Start with Activity 3, "Site Utilities."

Source: Contractor interviews/team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
7	Availability of labor
11	Quality of labor
18	General quality
22	Labor, union/non-union
26	Building code class
28	Type of contract
45	Facility type

Major BSI Components:

BSI	Description

None

Activity 2—Site Preparation

Factor Rules Applied:

2.1 If the confidence in subsurface conditions is low, then increase the duration of Site Preparation by 10 percent.

Source: Activity factor 3, "subsurface conditions."

2.2 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64, "weather delay factor."

2.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

2.4 If the project has less than one story below grade, then start-to-start with Activity 3, "Site Utilities." Set the lead of Site Utilities equal to 25 percent of the duration of Site Preparation.

Source: Activity factor 52, "stories below grade."

2.5 If the project has less than one story below grade, then finish-to-finish with Activity 3, "Site Utilities." Set the lag of Site Utilities equal to 10 percent of the duration of Activity 3, "Site Utilities."

Source: Activity factor 52, "stories below grade."

2.6 If the project has one or more stories below grade, then start-to-start with Activity 3, "Site Utilities." Set the lead of Site Utilities equal to 75 percent of the duration of Site Preparation.

Source: Activity factor 52, "stories below grade."

2.7 If the project has one or more stories below grade, then finish-to-finish with Activity 3, "Site Utilities." Set the lag of Site Utilities equal to 50 percent of the duration of Activity 3, "Site Utilities."

Source: Activity factor 52, "stories below grade."

2.8 If the project has a footprint-at-grade of less than 100,000 sq ft, then finish-to-start with Activity 4, "Foundation."

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

2.9 If the project has a footprint-at-grade of more than 100,000 sq ft, then start-to-start with Activity 4, "Foundation." Set the lead of Foundation equal to 50 percent of the duration of Site Preparation.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

2.10 If the project has a footprint-at-grade of more than 100,000 sq ft, the finish-to-finish with Activity 4, "Foundation." Set the lag of Foundation equal to 25 percent of the duration of Foundation.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
9	Volume of cut and fill
10	Total floor area
11	Quality of labor
15	Length of perimeter
17	Shape of floor plan
18	General quality of building
22	Labor, union/non-union
24	Total site area
26	Building code class
28	Type of contract
33	Area of paving
45	Facility type
49	Perimeter length
53	Floor-to-floor height below grade
61	Site work

Major BSI Components:

BSI	Description
14100	Clearing
14200	Demolition
14300	Site earthwork

Activity 3—Site Utilities

Factor Rules Applied:

3.1 If the project is located in a remote site, then increase the duration of Site Utilities by 10 percent

Source: Activity factor 12, "location."

3.2 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64, "weather delay."

3.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

3.4 If the footprint-at-grade is less than 100,000 sq ft, then finish-to-start with Activity 4, "Foundation."

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

3.5 If the footprint-at-grade is greater than 100,000 sq ft, then start-to-start with Activity 4, "Foundation." Set the lead of Foundation equal to 75 percent of the duration of Site Utilities.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

3.6 If the footprint-at-grade is greater than 100,000 sq ft, then finish-to-finish with Activity 4, "Foundation." Set the lag of Foundation equal to 50 percent of the duration of Foundation.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
9	Volume of cut and fill
11	Quality of labor
13	Supported floor area
15	Length of perimeter
17	Shape of floor plan
18	General quality of building
22	Labor union/non-union
24	Total site area
26	Building code class
28	Type of contract
30	Connected power load
45	Facility type
46	Heating energy source
47	Cooling energy source
49	Perimeter length
52	Stories below grade
53	Floor-to-floor height below grade
61	Sitework
66	Breakage

Major BSI Components:

BSI	Description
16100	Water supply and distribution
16200	Drainage and sewage systems
16300	Heating distribution systems
16400	Cooling distribution system
16500	Gas distribution system
16600	Exterior electrical

Activity 4—Foundation

Factor Rules Applied:

4.1 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64 "weather delay factor."

4.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

4.3 If the footprint-at-grade is less than 100,000 sq ft, then finish-to-start with Activity 5, "Structure."

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

4.4 If the footprint-at-grade is greater than 100,000 sq ft, then start-to-start with Activity 5, "Structure." Set the lead of Structure equal to 75 percent of the duration of Foundation.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

4.5 If the footprint-at-grade is greater than 100,000, then finish-to-finish with Activity 5, "Structure." Set the lag of Structure equal to 75 percent of the duration of Structure.

Source: Activity factors 23, "floor area at grade"; 48, "footprint area at grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
3	Subsurface conditions
7	Availability of labor
8	Type of foundation
10	Total floor area
11	Quality of labor
13	Supported floor area
15	Length of perimeter
17	Shape of floor plan
18	General quality of building
22	Labor union/non-union
24	Total site area
26	Building code class
28	Type of contract
45	Facility type
49	Perimeter length
50	Stories above grade
52	Stories below grade
53	Floor-to-floor height below grade
54	Piling depth

Major BSI Components:

BSI	Description
01100	Standard foundations
01200	Special foundations
01300	Slab on grade
01400	Basement excavation
01500	Basement walls

Activity 5—Structure

Factor Rules Applied:

5.1 Set the early start date of Structure equal to 60 days after the construction start date.

Source: Activity factor 63, "procurement delay."

5.2 If the project is located in a remote site, then increase the duration of Structure by 10 percent

Source: Activity factor 12, "remote location."

5.3 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64, "weather delay factor."

5.4 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

5.5 Finish-to-start with Activity 6, "Roofing."

Source: Contractor interview/Team meetings.

5.6 Start-to-start with Activity 7, "Exterior Closure." Set the lead of Exterior Closure equal to 75 percent of the duration of Structure.

Source: Contractor interview/Team meetings.

5.7 Finish-to-finish with Activity 7, "Exterior Closure." Set the lag of Exterior Closure equal to 75 percent of the duration of Exterior Closure.

Source: Contractor interview/Team meetings.

5.8 Finish-to-start with Activity 8, "Equipment."

Source: Contractor interview/Team meetings.

5.9 If the number of stories above grade is less than three, then finish-to-start with Activity 9, "Interior Construction."

Source: Activity factors 5, "number of floors"; 50 "stories above grade," 52, "stories below grade."

5.10 If the number of stories above grade is three or more, then start-to-start with Activity 9, "Interior Construction." Set the lead of Interior Construction equal to 30 percent of the duration of Structure.

Source: Activity factors 5, "number of floors"; 50 "stories above grade," 52, "stories below grade."

5.11 If the number of stories above grade is three or more, then finish-to-finish with Activity 9, "Interior Construction." Set the lag of Interior Construction equal to 30 percent of the duration of Interior Construction.

Source: Activity factors 5, "number of floors"; 50 "stories above grade"; 52, "stories below grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
4	Type of exterior cladding
7	Availability of labor
10	Total floor area
11	Quality of labor
13	Supported floor area
16	Story height
17	Shape of floor plan
18	General quality of building
20	Building volume
22	Labor union/non-union
26	Building code classification
28	Type of contract
45	Facility type
51	Floor-to-floor height above grade
53	Floor-to-floor height below grade
55	Number of stairwells
66	Breakage

Major BSI Components:

BSI	Description
02100	Floor construction
02200	Roof construction
02300	Stair construction

Activity 6—Roofing

Factor Rules Applied:

6.1 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, month construction begins; 64 weather delay factor.

6.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

6.3 If the number of stories above grade is less than three, then finish-to-start with Activity 9, "Interior Construction."

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

6.4 If the number of stories above grade is three or more, then start-to-start with Activity 9, "Interior Construction." Set the lead of Interior Construction equal to 75 percent of the duration of Roofing.

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

6.5 If the numbe. of stories above grade is three or more, then finish-to-finish with Activity 9, "Interior Construction." Set the lag of Interior Construction equal to 75 percent of the duration of Interior Construction.

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
7	Availability of labor
11	Quality of labor
17	Shape of floor plan
18	General quality of building
22	Labor, union/non-union
26	Building code class
27	Roof area
28	Type of contract
31	Type of roofing
39	R-value of insulation
42	Type of insulation
45	Facility type
66	Breakage

Major BSI Components:

BSI	Description
03100	Roofing

Activity 7—Exterior Closure

Factor Rules Applied:

7.1 If the exterior cladding type is specialized precast, then increase duration of Exterior Closure by 10 percent.

Source: Contractor interviews; Activity factors 4, "exterior cladding"; 7, "availability of labor"; 11, "quality of labor"; 22, "union, non-union"; 66, "breakage."

7.2 If the exterior cladding type is insulated board and if workers are unskilled, then increase the duration of Exterior Closure by 10 percent.

Source: Contractor interviews; Activity factors 4, "exterior cladding"; 7, "availability of labor"; 11, "quality of labor"; 22, "union, non-union"; 66, "breakage."

7.3 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64, "weather delay factor."

7.4 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

7.5 If the number of stories above grade is less than three, then finish-to-start with Activity 9, "Interior Construction."

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

7.6 If the number of stories above grade is three or more, then start-to-start with Activity 9, "Interior Construction." Set the lead of Interior Construction equal to 75 percent of the duration of Roofing.

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

7.7 If the number of stories above grade is three or more, then finish-to-finish with Activity 9, "Interior Construction." Set the lag of Interior Construction equal to 75 percent of the duration of Interior Construction.

Source: Activity factors 5, "number of floors"; 50 "stories above grade."

7.8 Finish-to-start with Activity 13, "Site Improvements."

Source: Contractor interview/team meetings.

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
14	Exterior wall area
18	General quality of the building
26	Building code classification
28	Type of contract
39	R-value of exterior insulation
42	Type of insulation
45	Facility type

Major BSI Components:

BSI	Description
04100	Exterior walls
04200	Exterior doors
04300	Exterior windows

Activity 8—Equipment

Factor Rules Applied:

8.1 If the project has elevators, then set the early start date of this activity equal to 200 days after the construction start date.

Source: Contractor interview; Activity factor 63, "procurement delay factor."

8.2 If the project has specialized equipment, then set the early start of this activity equal to 100 days after the construction start date.

Source: Contractor interview; Activity factor 63, "procurement delay factor."

8.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

8.5 Start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 75 percent of the duration of Equipment.

Source: Contractor interview/Team meetings.

8.6 Finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 75 percent of the duration of Interior Finish.

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
7	Availability of labor
11	Quality of labor
18	General quality of building
22	Labor, union/non-union
26	Building code class
28	Type of contract
45	Facility type
50	Stories above grade
52	Stories below grade
66	Breakage

MajorBSI Components:

BSI	Description
13100	Fixed and moveable equipment
13200	Furnishings
13300	Special construction
13400	Conveying systems

Activity 9—Interior Construction

Factor Rules Applied:

9.1 If the shape of the floor plan is not rectangular, then increase the duration of the activity by 10 percent.

Source: Activity factor 17, "shape of floor plan."

9.2 If the general quality of the building is high, then increase the duration of the activity by 5 percent.

Source: Activity factor 18, "general quality of building."

9.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

9.4 Start-to-start with Activity 10, "Mechanical Rough-In." Set the lead of Mechanical Rough-In equal to 50 percent of the duration of Interior Construction.

Source: Contractor interview/Team meetings.

9.5 Finish-to-finish with Activity 10, "Mechanical Rough-In." Set the lag of Mechanical Rough-in equal to 10 percent of Mechanical Rough-in.

Source: Contractor interview/Team meetings.

9.6 Start-to-start with Activity 11, "Electrical Rough-In." Set the lead equal of Electrical Rough-in to 50 percent of the duration of Interior Construction.

Source: Contractor interview/Team meetings.

9.7 Finish-to-finish with Activity 11, "Electrical Rough-In." Set the lag of Electrical Rough-in equal to 10 percent of Electrical Rough-in.

Source: Contractor interview/Team meetings.

9.8 If the number of floors is less than three, then finish-to-start with Activity 12, "Interior Finish."

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

9.9 If the number of floors is three or more, then start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 50 percent of the duration of Interior Construction.

Source: Activity factors 5, "number of floors"; 50 "stories above grade"; 52, "stories below grade."

9.10 If the number of floors is three or more, then finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 50 percent of the duration of Interior Finish.

Source: Activity factors 5, "number of floors"; 50 "stories above grade"; 52, "stories below grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
10	Total floor area
11	Quality of labor
16	Story height
22	Labor union/non-union
26	Building code class
28	Type of contract
29	Length of partitions
32	Presence of sprinklers
34	Type of doors
35	Type of interior partitions
45	Facility type
55	Number of stairwells
56	Average ceiling height
57	Percent full height partitions
66	Breakage

Major BSI Components:

BSI	Description
05100	Interior partitions, fixed
05200	Interior partitions, moveable
05300	Interior doors
05400	Interior windows

Activity 10—Mechanical Rough-In

Factor Rules Applied:

10.1 If the activity contains specialized or unusual air handling equipment, then the activity may not start until 120 days after the start of the project.

Source: Activity factor 63, "procurement delay factor."

10.2 If the interstitial space between floors is less than 4 feet, then increase the duration of the activity by 10 percent.

Source: Activity factors 51, "floor-to-floor height above grade"; 53, "floor-to-floor height below grade"; 56, "average ceiling height."

10.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

10.4 If the number of floors is less than three, then finish-to-start with Activity 12, "Interior Finish."

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

10.5 If the number of floors is three or more, then start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 50 percent of the duration of Mechanical Rough-in.

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

10.6 If the number of floors is three or more, then finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 50 percent of the duration of Interior Finish.

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
11	Quality of labor
17	Shape of floor plan
18	General quality of building
22	Labor union/non-union
25	HVAC requirements, tons
26	Building code classification
28	Type of contract
32	Presence of sprinklers
35	Type of interior partitions
43	Fire detectors required
45	Facility type
46	Heating energy source
47	Cooling energy source
57	Percent full height partitions
58	Plumbing
59	Heating BTUs
60	Cooling BTUs
66	Major BSI Components:

BSI	Description
08100	Sanitary systems
08200	Rainwater drainage
08300	Special plumbing systems
09100	Energy supply system
09200	Heating generation systems
09300	Cooling generation systems
09400	Air handling systems
09500	Ventilation systems
09600	Exhaust systems
09700	Special systems
10100	Fire protection systems
10200	Pool systems
10300	Pol systems
10400	Refrigeration systems
10500	Process systems
10600	Water/waste treatment system
10700	Chimneys and stacks
10800	Other misc. systems

Activity 11—Electrical Rough-In

Factor Rules Applied:

11.1 If the activity contains power generation or filtering equipment, then the activity cannot start until 200 days after the start of the project.

Source: Activity factor 63, "procurement delay factor."

11.2 If the interstitial space between floors is less than 4 feet, then increase the duration of the activity by 10 percent.

Source: Activity factors 51, "floor-to-floor height above grade"; 53, "floor-to-floor height below grade"; 56, "average ceiling height."

11.3 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

11.4 If the number of floors is less than three, then finish-to-start with Activity 12, "Interior Finish."

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

11.5 If the number of floors is three or more, then start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 50 percent of the duration of Electrical Rough-In.

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

11.6 If the number of floors is three or more, then finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 50 percent of the duration of Interior Finish.

Source: Activity factors 5, "number of floors"; 50, "stories above grade"; 52, "stories below grade."

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
10	Total floor area
11	Quality of labor
17	Shape of floor plan
18	General quality of building
22	Labor, union/non-union
25	HVAC requirements
26	Building code classification
28	Type of contract
30	Connected power load
35	Type of interior partitions
43	Fire detectors required
45	Type of facility
46	Heating energy source
47	Cooling energy source
57	Percent full height partitions
59	Heating BTUs
60	Cooling BTUs
66	Breakage

Major BSI Components:

BSI	Description
11100	Service and distrib. system
11200	Power systems
11300	Lighting systems
11400	Grounding systems
12100	Sound systems
12200	Alarm systems
12300	Television systems
12400	Control systems
12500	Hospital systems
12600	Time systems
12700	Electric heating systems
12800	Power generation systems

Activity 12—Interior Finish

Factor Rules Applied:

12.1 If the floor to ceiling height is greater than 10 ft, increase the duration of Interior Finish by 10 percent.

Source: Activity factor 56, "average ceiling height."

12.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

12.3 Start to start with activity 14, "Specialties/Furnishings." Set the lead of Specialties/Furnishings equal to 75 percent of the duration of Interior Finish.

Source: Contractor interview/Team meetings.

12.4 Finish-to-finish with Activity 14, "Specialties/ Furnishing." Set the lag of Specialties/Furnishings equal to 25 percent of the duration of Specialties/Furnishings.

Source: Contractor interview/Team meetings.

12.5 Start-to-start with Activity 15, "Mechanical Finish." Set the lead of Mechanical Finish equal to 50 percent of the duration of Interior Finish.

Source: Contractor interview/Team meetings.

12.6 Finish-to-finish with Activity 15, "Mechanical Finish." Set the lag of Mechanical Finish equal to 10 percent of the duration of Mechanical Finish.

Source: Contractor interview/Team meetings.

12.7 Start-to-start with Activity 16, "Electrical Finish." Set the lead of Electrical Finish equal to 50 percent of the duration of Interior Finish.

Source: Contractor interview/Team meetings.

12.8 Finish-to-finish with Activity 16, Electrical Finish. Set the lag of Electrical Finish equal to 10 percent of the duration of Electrical Finish.

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
4	Exterior cladding
7	Availability of labor
10	Total floor area
11	Quality of labor
16	Story height
17	Shape of floor plan
18	General quality of building
21	Finished floor area
22	Labor union/non-union
26	Building code class
28	Type of contract
29	Length of partitions
32	Presence of sprinklers
34	Type of doors
35	Type of interior partitions
38	Type of ceiling finish
40	Type of interior wall finish
41	Type of floor finish
45	Facility type
46	Heating energy source
47	Cooling energy source
51	Floor-to-floor height above grade
53	Floor-to-floor height below grade
55	Number of stairwells
57	Percent full height partitions
66	Breakage

Major BSI Components:

BSI	Description
06100	Wall finishes
06200	Flooring and floor finishes
06300	Ceilings and ceilings finishes

Activity 13—Site Improvements

Factor Rules Applied:

13.1 If the activity is delayed over 25 percent due to weather, then delay the start of the activity until the weather delay is less than 25 percent of the duration.

Source: Activity factors 6, "month construction begins"; 64, "weather delay factor."

13.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

13.3 Finish to start with Activity 17, "End Job."

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
1	Type of structure
2	Owner's schedule
7	Availability of labor
9	Volume of cut/fill
11	Quality of labor
17	Shape of floor plan
18	General quality
22	Labor, union/non-union
24	Total site area
26	Building code class
28	Type of contract
33	Area of paving
36	Area of landscaping
45	Facility type
61	Sitework

Major BSI Components:

BSI	Description
15100	Pavements
15200	Site development
15300	Landscaping

Activity 14—Specialties/Furnishings

Factor Rules Applied:

14.1 If hospital equipment is being installed, then add 10 percent to Specialties/Furnishings' duration.

Source: Activity factor 26, "building code class."

14.2 If modular furnishings are being installed, then add 10 percent to Specialties/Furnishings' duration.

Source: Activity factor 35, "type of interior partitions."

14.3 If the floor plan is not rectangular, then add 10 percent to Specialties/Furnishings' duration.

Source: Activity factor 17, "shape of floor plan."

14.4 If the Type of Interior Partitions, Type of Interior Wall Finish, or Type of Interior Floor Finish are unusual, then add 10 percent to Specialties/Furnishings' duration.

Source: Activity factors 35, "type of interior partitions"; 40, "type of interior wall finish"; 41, "type of interior floor finish."

14.5 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

14.6 Finish-to-start with Activity 17, "End Job."

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
5	Number of floors
7	Availability of labor
10	Total floor area
11	Quality of labor
18	General quality of building
21	Finished floor area
22	Labor union/non-union
28	Type of contract
45	Facility type
63	Procurement time
66	Breakage

Major BSI Components:

BSI	Description
07100	Toilet and bath specialties
07200	Cabinetry
07300	Shelving
07400	Other specialties

Activity 15—Mechanical Finish

Factor Rules Applied:

15.1 If the project contains "intelligent" control systems, then increase the duration of Mechanical Finish by 10 percent.

Source: Contractor interview.

15.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

15.3 Finish-to-start with Activity 17, "End Job."

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
7	Availability of labor
10	Total floor area
11	Quality of labor
17	Shape of floor plan
18	General quality of building
22	Labor union/non-union
25	HVAC requirements, tons
26	Building code classification
28	Type of contract
32	Presence of sprinklers
35	Type of interior partitions
38	Type of interior wall finish
43	Fire detectors required
45	Facility type
46	Heating energy source
47	Cooling energy source
57	Percent full height partitions
58	Plumbing fixtures
59	Heating BTUs
60	Cooling BTUs
66	Breakage

Major BSI Components:

BSI	Description
08400	Special plumbing fixtures
09100	Energy supply system
09200	Heating generation systems
09300	Cooling generation systems
09400	Air handling systems
09500	Ventilation systems
09600	Exhaust systems
09700	Special systems
09800	Controls and instrumentation
09900	Testing, balance, etc.
10100	Fire protection systems
10200	Pool systems
10300	Pol systems
10400	Refrigeration systems
10500	Process systems
10600	Water/waste treatment system
10700	Chimneys and stacks
10800	Other misc. systems

Activity 16—Electrical Finish

Factor Rules Applied:

16.1 If the project contains backup power systems, then increase the duration of Electrical Finish by 10 percent.

Source: Contractor interview/Team generated factor.

16.2 If the activity is originally scheduled in a split configuration, then delay the activity until the activity is not split.

Source: Activity factor 65, "productivity factor."

Sequence Rules:

16.3 Finish-to-start with Activity 17, "End Job."

Source: Contractor interview/Team meetings.

Unapplied Factors:

Factor Number	Description
2	Owner's schedule
7	Availability of labor
10	Total floor area
11	Quality of labor
17	Shape of floor plan
18	General quality of building
22	Labor union/non-union
26	Building code classification
28	Type of contract
30	Connected power load
35	Type of interior partitions
38	Type of ceiling finish
40	Type of interior wall finish
43	Fire detectors required
45	Facility type
46	Heating energy source
47	Cooling energy source
57	Percent full height partitions
59	Heating BTUs
60	Cooling BTUs
66	Breakage

Major BSI Components:

BSI	Description
11100	Service and distrib. system
11200	Power systems
11300	Lighting systems
11400	Grounding systems
12100	Sound systems
12200	Alarm systems
12300	Television systems
12400	Control systems
12500	Hospital systems
12600	Time systems
12700	Electric heating systems
12800	Power generation systems

Activity 17—End Job

Factor Rules Applied:

None

Sequence Rules:

End Job is the Final Activity in the schedule.

Unapplied Factors:

None

Major BSI Components:

None

Generic Steel Structure Network

Figure 7 shows a generic network for the steel frame building. This precedence diagram is somewhat different from typical diagrams since the relationships are not fixed. The relationship lines are conditional on specific building or activity parameters. These conditional situations were identified in the previous set of activity descriptions.

For the sake of clarity, not all logic ties between activities are shown on the diagram. The reader should be sure to read the key in order to allow cross-referencing with the activity descriptions.

3 CASE STUDIES

This chapter illustrates the practical application of the activity factors and the sequence descriptions provided in Chapter 2. The first section of this chapter provides a procedure for how the factors and sequences may be applied. The next three sections of the chapter show how the whole procedure was applied to a specific project. With each of the applications the project data was provided as input.

The Appendix to this report briefly discusses how the approximate durations for individual activities were developed based on initial data from the CEG/CACES system. These approximate durations were developed to demonstrate the application of the approach taken here.

Procedural Description

The procedure developed to obtain activity durations is outlined in Table 7. The general outline of the procedure is to establish the early start, lead, duration, and lag for an activity and then to calculate the early finish for the activity. The weather and productivity activity factors are then applied. Finally, the dates from the activity are posted to the following activities via the sequence factors. The process proceeds as follows:

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

3. Evaluate lags to determine one set of possible early finish dates.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

The first step in the procedure is to determine the latest that an activity can start. This step is broken into two tasks. The first task is to have the early start dates and leads posted from previous activities available for the current activity. This may be accomplished by storing a list of all pairs of early start dates and leads that have been posed from prior activities. The second step in the procedure is to select the combination of early start dates and lead durations that gives the latest activity start date. This activity start date will also be stored for later use.

There is one exception to the first procedure discussed in the previous paragraph, dealing with the start of the project. If the activity is the first in the schedule, i.e., Activity 1, "Start Job," then an

initializing procedure will store the project start date in the list of early start dates and leads from prior activities.

The second step in the procedure is to determine the duration of the activity. This is accomplished by first obtaining the originally estimated activity duration from input and then applying the appropriate activity factors to obtain several potential durations. The longest of these impacted durations is then stored for further processing.

The third and fourth steps develop the list of possible early finish dates. The third step obtains its early finish date candidates from the finish-to-finish (and lag durations) of previous activities. The fourth step calculates its early finish date candidates by adding the current activity duration to the start-to-start (and lead duration) or finish-to-start relationships from previous activities.

The fifth step determines the estimated finish date for the activity. This is accomplished by selecting the latest date from the potential activity completion dates provided in steps three and four.

The sixth step of the procedure is to evaluate the impact of the weather and productivity activity factors on the activity. These factors may require that the activity's early start date be delayed either to decrease the impact of bad weather or to improve the productivity of the work force. If the early start date is delayed, then the early finish date of the activity that was calculated in step 4 will be modified to reflect the activity's revised early start date. The weather and productivity activity factors may be applied several times until the conditions of these factors are met.

Since weather and productivity factors may only be applied after the initial timing of an activity has been determined, weather and productivity are processed in the sixth step.

The seventh, and final, step, in the procedure is to apply the sequence rules and post appropriate early start dates and lead durations to the following activities. The next activity is then selected and processed according to steps 1 through 6.

When the last activity in the schedule, i.e., Activity 17, "End Job" has been reached, then the finish date of the activity becomes the finish date for the project. When the project finish date has been determined, the procedure will be completed.

Introduction to the Case Studies

The project selected for the following case studies was a Barracks building constructed at Fort Irwin, CA. Three cases are provided, each with a different structural system. The first case study uses a steel-framed structure; the second case involves a masonry structure; the third case is based on a reinforced concrete structure.

Each case is organized in three parts. The first part of each case introduces the activity durations and factor values used as input to the system. The second part of the case applies the procedure discussed in the previous section of this chapter to determine estimated contract durations. The third part provides a discussion of the effectiveness of the procedural application of the activity factors and sequences.

Case Study One: Steel Structure

Tables 8 and 9 provide the input to the application of activity durations and factors to the procedure discussed in the first section of this Chapter. The underlined items in Table 8 illustrate the items that were changed for each of the three cases.

The next several pages demonstrate the application of the activity initial durations and factor quantities to the steel-framed structure. The schedule was calculated with a 5-day work week and the following holidays: 15 January (Martin Luther King's Day), 19 February (President's Day), 28 May (Memorial Day), and 4 July (Independence Day).

Figure 8 provides a bar chart of the results of this case study.

Activity 1—Start Job

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations. Since this is the first activity, the start date of the activity will be set to be the start date of the project, i.e., 2 January 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration. Apply factor 1.2 to obtain a duration of 15 working days.

3. Evaluate lags to determine one set of possible early finish dates. No lags are present.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2. The only activity early finish date is obtained by adding 15 working days to the start date of 1 January. This results in a possible finish date of 23 January 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4, and set the latest finish date found as the activity completion date. From step 4, activity completion date is 23 January 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

No weather or productivity impacts since the project is located in California desert.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list. Apply 1.3 and post an early start date of 24 January 1990 to Activity 2, "Site Preparation." Apply 1.4 and post an early start date of 24 January 1990 to Activity 3, "Site Utilities."

Activity 2—Site Preparation

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 1, the start date is 24 January 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

Table 7

Factor Quantities for Steel Structure

Number	Factor	Quantity
1	Type of structural frame	Steel
2	Owner's schedule	To be determined
3	Subsurface conditions	Not unusual
4	Type of exterior cladding	Dryvitt board
5	Number of floors	3
6	Month construction begins	November
7	Availability of labor	Labor available
8	Type of foundation	Column
9	Volume of cut/fill	1000 cy.yd.
10	Total floor area	23,000 sq ft
11	Quality of labor	Average
12	Location, city	Fort Irwin, CA
13	Supported floor area	23,000 sq ft
14	Exterior wall area	19,000 sq ft
15	Length of perimeter	600 ft
16	Story height	9 ft
17	Story height	9 ft
18	Shape of floor plan	Rectangular/irregular
19	General quality of building	Typical
20	Building volume	230,000 cy.ft
21	Finished floor area	80% of item 20
22	Labor: union/non-union	Union
23	Floor area on grade	8200 sq ft
24	*Total site area*	110% of item 23
25	Hvac requirements, tons	See 59/60 below
26	Building code class	Siesmic
27	Roof area	9600 sq ft
28	Type of construction contract	Fixed price
29	Length of partitions	1518
30	Connected power load	Unknown
31	Type of roofing	Shingled
32	Presence of sprinklers	No
33	Area of paving	37,500 sq ft
34	Type of doors	1 hour
35	Type of interior partitions	Metal stud/gypboard
36	Area of landscaping	4,200 sq ft
37	Number of occupants	136
38	Type of ceiling finish	Suspended gypboard
39	R-value of exterior wall	11
40	Type of interior wall finish	Paint
41	Type of floor finish	Vinyl tile
42	Type of insulation	Panels/blown
43	Fire detectors required	Smoke alarms
44	Gross floor area	23,000 sq ft
45	Facility type	Barracks
46	Heating energy source	Steam
47	Cooling energy source	Chilled water
48	Footprint area at grade	8200 sq ft
49	Facility perimeter length	600 ft
50	Stories above grade	3
51	Floor-to-floor height above grad	9 ft
52	Stories below grade	0
53	Floor-to-floor height below grade	N/A

Table 7 (Cont'd)

Number	Factor	Quantity
54	Piling depth	N/A
55	Number of stairwells	2
56	Average ceiling height	8 ft
57	Percent full height partitions	99%
58	Plumbing Fixtures	180 pieces
59	Heating BTU	290,472 BTU
60	Cooling BTU	441,233 BTU
61	Sitework	1000 cu yd

The original duration of 4 working days does not change since factor 2.1 does not apply.

3. Evaluate lags to determine one set of possible early finish dates.

No lags are present.

4. Determine the activity's possible early finish dates based upon the latest activity start from step 1, and the activity duration from step 2.

The start date from step 1, and the activity duration from step 2 yield a possible finish date of 29 January 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

From step 4, the activity completion date is 29 January 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

No weather or productivity impacts, since the project is located in California desert.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

The project has less than one story below grade; therefore sequence rules 2.4 and 2.5 fire.

2.4 Post an early start date of 30 January 1990 to Activity 3, "Site Utilities." Set lead equal to 25 percent of duration from step 2, or 1 working day.

2.5 Post finish date of 29 January 1990 to Activity 3, "Site Utilities." Set lag equal to 25 percent of duration of Site Utilities, or 2 working days.

Table 8

Activity Durations for Steel Structure

Number	Description	Duration
1	Start job	0
2	Site preparation	4
3	Site utilities	7
4	Foundation	6
5	Structure	30
6	Roofing	20
7	Exterior closure	28
8	Equipment	0
9	Interior construction	25
10	Mechanical rough-in	22
11	Electrical rough-in	28
12	Interior finish	34
13	Site improvements	10
14	Specialties/furnishing	2
15	Mechanical finish	8
16	Electrical finish	15
17	End job	0

The project has less than 10,000 sq ft of footprint at grade; therefore sequence rule 2.8 fires.

2.8 Post an early start date of 29 January 1990 to Activity 4, "Foundation."

Activity 3—Site Utilities

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 1, the start date is 24 January 1990. From Activity 2, the start date is 30 January plus 1 day lead (rule 2.4), yielding a start date of 31 January 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 7 working days is changed since factor 3.1, "remote location," fires, increasing the duration of the activity by 10 percent. The revised duration of the activity is 8 days.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 2, "Site Preparation," one possible early finish date is 29 January 1990 (rule 2.8) and the lag is 2 working days. This yields one possible finish date of 31 January 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

The start date from step 1, and the activity duration from step 2 yields a possible finish date of 9 February 1990.

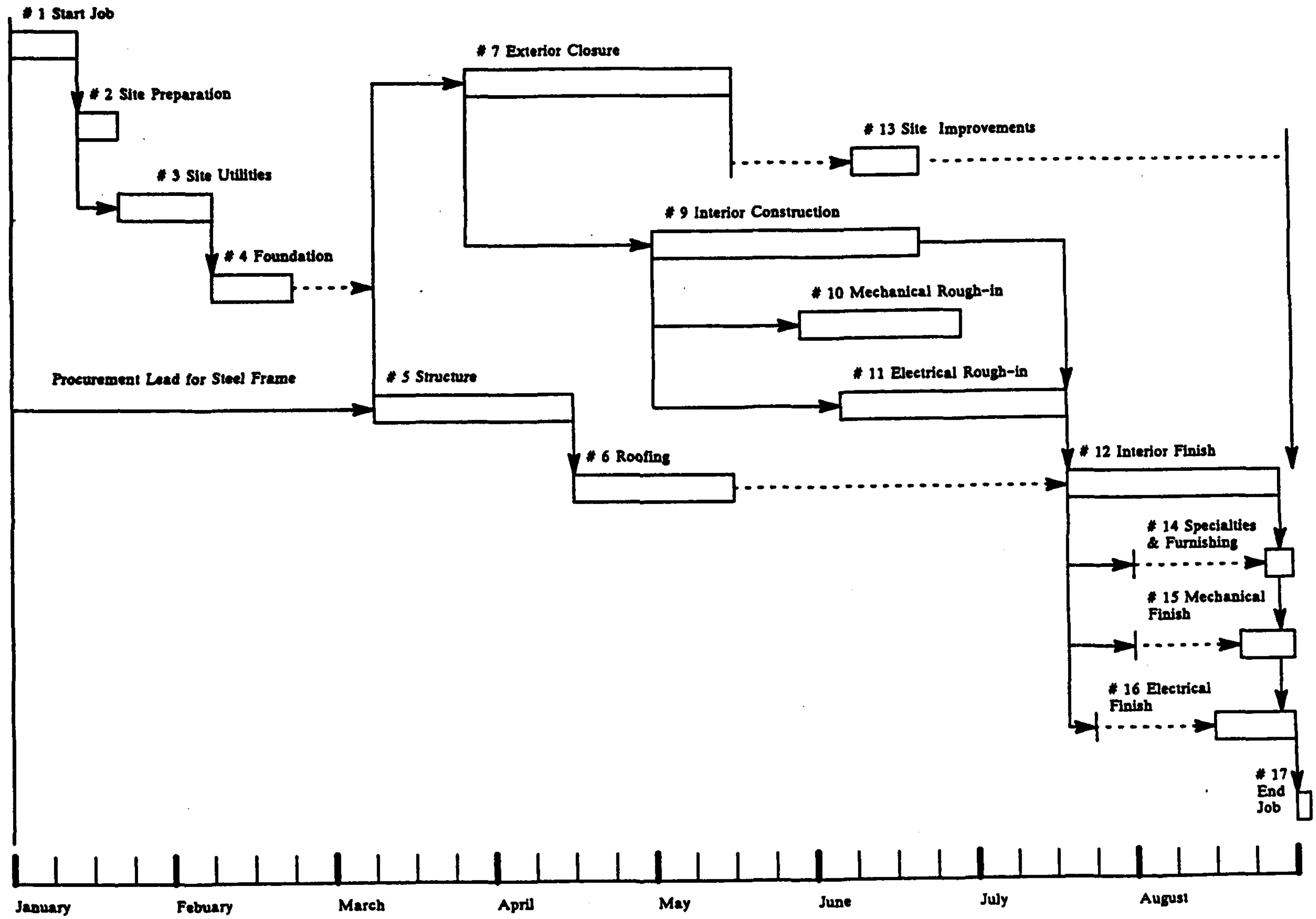


Figure 8. Steel Structure Schedule.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

From step 4 the activity completion date is 9 February 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

No weather impacts, project located in California desert. No productivity delay.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

The project has less than 10,000 sq ft of footprint at grade, therefore sequence rule 3.4 fires.

3.4 Post a start date of 12 February 1990, to Activity 4, "Foundation."

Activity 4—Foundation

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 2, "Site Preparation," (rule 2.8) becomes 29 January 1990. From Activity 3 (rule 3.4), the start date is 12 February 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The originally estimated duration is 6 working days.

3. Evaluate lags to determine one set of possible early finish dates. None.

4. Determine the activity's possible early finish dates based upon the latest activity start from step 1, and the activity duration from step 2.

The completion date is calculated to be 20 February 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is calculated to be 20 February 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather productivity impacts since the project is located in California desert.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

The project has less than 10,000 sq ft of footprint at grade; therefore sequence rule 4.3 fires.

4.3 Post an early start date of 21 February 1990 to Activity 5, "Structure."

Activity 5—Structure

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 4, "Foundation" (rule 4.3), the start date becomes 21 February 1990.

From rule 5.1, the structure cannot start until 60 calendar days after project start: 5 March 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 30 working days is extended 10 percent for being in a remote site (rule 5.2). The duration is 33 working days.

3. Evaluate lags to determine one set of possible early finish dates.

There are no lags.

4. Determine the activity's possible early finish dates based upon the latest activity start from step 1, and the activity duration from step 2.

An initial early start date of 5 March 1990 and 33 working days yields an early start date of 18 April 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date becomes 18 April 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather or productivity impacts since the project is located in California desert.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 5.5, post a start date to Activity 6, "Roofing," of 19 April 1990.

From rule 5.6, post a start date to Activity 7, "Exterior Closure," of 5 March 1990. Set the lead equal to 75 percent of the duration of Structure, or 25 working days.

From rule 5.7, post a finish date to Activity 7, "Exterior Closure," of 18 April 1990. Set the lag equal to 75 percent of the duration of Exterior Closure, or 21 days.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list (cont).

From rule 5.8 post a start date to Activity 8, "Equipment," of 19 April 1990.

From rule 5.9 post a start date to Activity 9, "Interior Construction," of 19 April 1990.

Activity 6—Roofing

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

Determine the start date from Activity 5, "Structure" (rule 5.5) to be 19 April 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration estimate is not changed, i.e., it is still 20 working days.

3. Evaluate lags to determine one set of possible early finish dates.

There are no lags.

4. Determine the activity's possible early finish dates based upon the latest activity start from step 1, and the activity duration from step 2.

An initial early finish date of 19 April 1990 and 20 working days yields an early finish date of 16 May 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The early finish date becomes 16 May 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather impacts since the project is located in the California desert. No productivity delay.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 6.4, post a start date to Activity 12, "Interior Finish," of 19 April 1990. Set the lead equal to 75 percent of Roofing duration, or 15 working days.

From rule 6.5 post a finish date to Activity 12, "Interior Finish," of 16 May 1990. Set the lag equal to 75 percent of Interior Finish Duration, or 26 working days.

Activity 7—Exterior Closure

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 5, "Structure" (rule 5.6), the start date is 5 March 1990; a lead of 25 working days yields a work start of 9 April 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

Rule 7.2 is applicable but does not fire. The original duration estimate is not changed from 28 working days.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 5, "Structure" (rule 5.7), the finish date is 18 April 1990. Adding a lag of 21 days yields a work finish date of 16 May 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

An initial early finish date of 9 April 1990 and 28 working days yields an early finish date of 17 May 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 17 May 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather impacts since the project is located in the California desert. There is no productivity delay.*

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 7.6, post a start date to Activity 9, "Interior Construction" of 9 April 1990. Set the lead equal to 75 percent of Exterior Closure duration, or 21 working days.

From rule 7.7, post a finish date to Activity 9, "Interior Construction," of 17 May 1990. Set the lag equal to 75 percent of Interior Construction duration, or 19 working days.

From rule 7.8 post a start date to Activity 13, "Site Improvements" of 17 May 1990.

* Notice that if Activity 7's duration had been 2 days less, then the lag from Activity 5 would have controlled the finish date. If that were the case, then the productivity rule would have moved the start of Activity 7 back to maintain continuous work flow.

Activity 8—Equipment

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 5, "Structure" (rule 5.8), set the start date to 9 April 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

Since this activity's duration is zero, stop processing this activity and do not include the activity in the final schedule produced.

3. Evaluate lags to determine one set of possible early finish dates.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

Activity 9—Interior Construction

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 7, "Exterior Closure" (rule 7.7), set the start date of 9 April 1990, and the lead equal to 21 working days. The work start date is 8 May 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 25 working days is modified by rule 9.1 since the shape of the floor plan is not rectangular, yielding a revised duration of 10 percent higher or 28 days.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 7, "Exterior Closure" (rule 7.7), the finish date is 17 May 1990 and lag is 19 working days. The new finish date is 13 June 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

An initial early finish date of 8 May 1990 and 28 working days yields an early finish date of 15 June 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 15 June 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather impacts.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 9.4, post a start date to Activity 10, "Mechanical Rough-In," of 10 May 1990. The lead is equal to 50 percent of Interior Construction, or 14 working days.

From rule 9.5, post a finish date to Activity 10, "Mechanical Rough-In," of 18 June 1990. The lag is equal to 10 percent of Mechanical Rough-In, or 2 working days.

From rule 9.6, post a start date to Activity 10, "Electrical Rough-In," of 10 May 1990. The lead is equal to 50 percent of Interior Construction, or 14 working days.

From rule 9.7, post a finish date to Activity 10, "Electrical Rough-In," of 18 June 1990. The lag is equal to 10 percent of Electrical Rough-In, or 6 working days.

From rule 9.9, post a start date to Activity 12, "Interior Finish," of 10 May 1990. The lead is equal to 50 percent of Interior Construction, or 14 working days.

From rule 9.10, post a finish date to Activity 12, "Interior Finish," of 18 June 1990. The lag is equal to 50 percent of Interior Finish, or 17 working days.

Activity 10—Mechanical Rough-in

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 9, "Interior Construction," (rule 9.4), the start date is 10 May 1990 and the lead is 14 working days, creating a work start date of 31 May 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 22 days is not changed. Rule 10.2 was partially triggered since the interstitial space is less that 4 ft; however, no ductwork is used so the rule did not fire.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 9, "Interior Construction" (rule 9.5), there is a finish date of 18 June 1990 and a lag of 2 working days, creating a finish date of 20 June 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

An initial early finish date of 31 May 1990 and 22 working days yields an early finish date of 29 June 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 29 June 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather or productivity impacts.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 10.4, post a start date to Interior Finish of 30 June 1990.

Activity 11—Electrical Rough-In

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 9, "Interior Construction" (rule 9.4), assign a start date of 10 May 1990 and a lead of 14 working days, creating a work start date of 31 May 1990.

Revised work start date is based upon the iterative procedures discussed in step six, below.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 28 days is not changed. Rule 11.2 was applied since the interstitial space is less than 4 ft; however, no ductwork is used so the rule did not fire.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 9, "Interior Construction" (rule 9.5), assigns a finish date of 18 June 1990 and a lag of 14 working days, creating a finish date of 16 July 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start from step 1, and the activity duration from step 2.

An early finish date of 31 May 1990 and 28 working days yields an early finish date of 10 July 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 16 July 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

The productivity factor provides an impact here. The difference between the work start from step 1 (31 May 1990), and completion date from step 5 (16 July 1990) is 32 working days. The activity only takes 28 working days; therefore move the work start date back to 16 July 1990 minus 28 working days, or 6 June 1990.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 11.4, post a start date to Interior Finish of 16 July 1990.

Activity 12—Interior Finish

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 6, "Roofing" (rule 6.4), set a start date of 19 April 1990 and a lead of 15 working days. The work start date is 10 May 1990.

From Activity 9, "Interior Construction" (rule 9.9), set a start date of 10 May 1990 and a lead of 14 working days. The work start date is 30 May 1990.

From Activity 10, "Mechanical Rough-In" (rule 10.4), set a start date of 30 June 1990.

From Activity 11, "Electrical Rough-In" (rule 11.4), set a start date of 16 July 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 34 days is not modified.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 6, "Roofing" (rule 6.5), set a finish date of May 16, 1990 and a lag of 26 working days. The finish date is 12 June 1990.

From Activity 9, "Interior Construction" (rule 9.10), set a finish date of 18 June 1990 and a lag of 17 working days. The finish date is 11 July 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

A possible early finish date of 16 July 1990 and 34 days yields a completion date of 30 August 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 30 August 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather or productivity impacts.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 12.3, post a start date to Activity 14, "Specialties/Furnishings," of 17 July 1990. The lead duration is 75 percent of Interior Finish, or 26 working days.

From rule 12.4, post a finish date to Activity 14, "Specialties/Furnishings," of 30 August 1990. The lag duration is 25 percent of Specialties/Furnishings, or 1 day.

From rule 12.5, post a start date to Activity 15, "Mechanical Finish," of 17 July 1990. The lead duration is 50 percent of Interior Finish, or 17 working days.

From rule 12.6, post a finish date to Activity 15, "Mechanical Finish," of 30 August 1990. The lag duration is 10 percent of Mechanical Finish, or 1 day.

From rule 12.7, post a start date to Activity 16, "Electrical Finish," of 17 July 1990. The lead duration is 50 percent of Interior Finish, or 17 working days.

From rule 12.8, post a finish date to Activity 16, "Electrical Finish," of 30 August 1990. The lag duration is 10 percent of Electrical Finish, or 2 days.

From rule 12.9, post a start date to Activity 17, "End Job," of 31 August 1990.

Activity 13—Site Improvements

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 7, "Exterior Closure" (rule 7.8), set a start date of 17 May 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 10 days is not modified by activity factors.

3. Evaluate lags to determine one set of possible early finish dates.

There are no lags.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

A possible early finish date of 17 May 1990 and a 10 day duration yields 31 May 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date is 31 May 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather or productivity impacts.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 13.3, post a start date to Activity 17, "End Job," of 31 May 1990.

Activity 14—Specialties/Furnishings

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 12, "Interior Finish" (rule 12.3), set a start date of 17 July 1990 and a lead of 26 working days, creating a work start date of 22 August 1990.

The start date is modified to 28 August 1990 due to productivity factor (rule 14.5) in step 6, below.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 2 days is not modified by activity factors.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 12, "Interior Finish" (rule 12.4), set a finish date of 30 August 1990 and a lag duration of 1 working day, creating a work finish date of 30 August 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

An early finish date of 22 August 1990 and 2 working days creates a new early finish date of 24 August 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The completion date from step 3 is 30 August 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

The productivity factor provides an impact here. The difference between the work start from step 1, 22 August 1990, and the completion date from step 5, 30 August 1990 is 32 working days. The

activity only takes 2 working days, therefore move the work start date back to 30 August 1990 minus 2 working days, or 28 August 1990.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 14.6, post a start date to Activity 17, "End Job," of 31 August 1990.

Activity 15—Mechanical Finish

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 12, "Interior Finish," (rule 12.5), set a start date of 17 July 1990 and a lead duration of 17 working days, creating a work start date of 9 August 1990.

The start date is modified to 21 August 1990 due to productivity factor (rule 15.2) in step 6, below.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 8 days is not modified by activity factors.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 12, "Interior Finish," (rule 12.6), set a finish date of 30 August 1990 and a lag duration of 1 day, creating a work finish date of 30 August 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

A possible early finish date of 8 August 1990 and 8 working days yields a possible finish date of 17 August 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

Set a completion date of 30 August 1990, from step 3.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

The productivity factor provides an impact here. The difference between the work start from step 1, 9 August 1990, and the completion date from step 5, 30 August 1990 is 16 working days. The activity only takes 8 working days; therefore move the work start date back to 30 August 1990 minus 8 working days, or 21 August 1990.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 15.3, post a start date to Activity 17, "End Job," of 31 August 1990.

Activity 16—Electrical Finish

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 12 "Interior Finish" (rule 12.6), set a start date of 17 July 1990 and a lead duration of 17 working days, creating a work start date of 9 August 1990.

The start date is modified to 13 August 1990 due to productivity factor (rule 16.2) in step 6, below.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

The original duration of 15 working days is not modified by activity factors.

3. Evaluate lags to determine one set of possible early finish dates.

From Activity 12, "Interior Finish" (rule 12.7), set a finish date of 30 August 1990 and a lag duration of 2 days, creating a work finish date of 31 August 1990.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

A possible early finish date of 9 August 1990 and 15 working days yields a completion date of 29 August 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

Set a completion date of 31 August 1990 from step 3.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

The productivity factor provides an impact here. The difference between the work start from step 1, 9 August 1990, and the completion date from step 5, 31 August 1990 is 17 working days. The activity only takes 15 working days; therefore move the work start date back to 30 August 1990 minus 8 working days, or 13 August 1990.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

From rule 16.3, post a start date to Activity 17, "End Job," of 4 September 1990.

Activity 17—End Job

1. Determine the start date of an activity by selecting the latest combination of early start dates and lead durations.

From Activity 12, "Interior Finish" (rule 12.9), set a start date of 31 August 1990.

From Activity 13, "Site Improvements" (rule 13.3), set a start date of 31 May 1990.

From Activity 14, "Specialties/Furnishings" (rule 14.6), set a start date of 31 August 1990.

From Activity 15, "Mechanical Finish" (rule 15.3), set a start date of 31 August 1990.

From Activity 16, "Electrical Finish" (rule 16.3), set a start date of 4 September 1990.

2. Apply activity factors to the original activity duration and set the longest duration as the activity duration.

There are no activity factors.

3. Evaluate lags to determine one set of possible early finish dates.

There are no lags.

4. Determine the activity's possible early finish dates based upon the latest activity start, from step 1, and the activity duration, from step 2.

The possible early finish date becomes 4 September 1990.

5. Evaluate the activity's possible early finish dates from steps 3 and 4 and set the latest finish date found as the activity completion date.

The possible early finish date becomes 4 September 1990.

6. Determine the impacts of weather and productivity and recalculate the activity's start and finish dates if appropriate.

There are no weather or productivity impacts.

7. Apply sequence rules and post the appropriate dates from the activity to all following activities and proceed to the next activity in the list.

Post 4 September 1990 to the project completion date.

Figure 8, the steel structure schedule, shows the result of applying specific project characteristics to the generic steel structure from Figure 7. Each activity is shown as a time-scale bar.* Although the time scaling is not exact, it shows the relative durations of the activities and their driving logical relationships. The logical sequence that places an activity in the schedule are shown as solid arrows.

*Activity 8, "Equipment," had zero duration and was not included.

Several activities also have dashed arrows. These dashed arrows show the effect of factor rules. In the case of Activity 4, "Foundation," the float is caused because steel procurement delays the start of Activity 5, "Structure." In the case of Activities 14, 15, and 16, the dashed line shows the effect of the productivity factor. These three activities could have started at the end of the solid arrow during the second week of August; however, to provide a non-split schedule, the activity start was delayed to that shown in the figure.

The case study also shows that a simple modification to the productivity rule should be considered. The productivity rule that was used for the case study is very simple. If there is a productivity delay, then correct it. In some cases, however, a small productivity delay will be acceptable if the overall completion time of the project is decreased. The productivity rule could, therefore, be modified to correct productivity delays if the overall project duration will be increased or if some reasonable threshold has been exceeded. Using the threshold method, the productivity rule would take effect only if the productivity delay was greater than 25 percent of the duration of the activity. Specific customizations could then be made for specific activities.

Based on this case study, it appears that the application of factor rules and conditional sequencing to activities may provide a powerful assistant for project managers. An implementation of this approach should be able to quickly produce a rough cut schedule based on the specifics of the project at hand.

Case Study Two: Masonry Structure

This section of the report provides the results of evaluating the activity factor model in the context of a masonry structure. Tables 9 and 10 gives the factor values and durations for the activities in the masonry structure, and lists the changes required to adapt the steel network to a masonry structure. Differences between the steel structure activities reflect the logic implied in the masonry structure.

One of the most important logic differences between the masonry structure and the steel structure is that, in the masonry structure, the mechanical and electrical rough-in activities normally begin concurrently with the structure. This is because the conduit needed for the mechanical and electrical systems is typically imbedded within the masonry structure. In the steel structure, the pipe and conduit is usually contained within steel stud walls.

Another significant logic change that occurs when adapting the steel network to the masonry structure is that the masonry structure generally has no stud wall construction. This change is also reflected in the sequence rules listed in the activity descriptions for the masonry structure.

For the sake of clarity, the complete sequence of determining the overall completion date is not provided. Figures following the activity descriptions provide the generic masonry network and the schedule that resulted from the activity factors and the duration data.

Activity 5—Structure

Factor Rules Applied:

5.1 Steel factor rule 5.1 is not appropriate for masonry structure since there is no procurement delay for masonry.

5.2 Steel factor rule 5.2 is not appropriate for masonry structure since a remote location should not effect deliveries and productivity of masons.

Table 9

Factor Quantities for Masonry Structure

Number	Factor	Quantity
1	Type of structural frame	Masonry
2	Owner's schedule	To be determined
3	Subsurface conditions	Not unusual
4	Type of exterior cladding	Stucco
5	Number of floors	3
6	Month construction begins	November
7	Availability of labor	Labor available
8	Type of foundation	Continuous
9	Volume of cut/fill	1000 cu yd
10	Total floor area	23,000 sq ft
11	Quality of labor	Average
12	Location, city	Fort Irwin, CA
13	Supported floor area	23,000 sq ft
14	Exterior wall area	19,000 sq ft
15	Length of perimeter	600 ft
16	Story height	9 ft
17	Story height	9 ft
18	Shape of floor plan	rectangular/irregular
19	General quality of building	typical
20	Building volume	230,000 cu ft
21	Finished floor area	80% of item 20
22	Labor: union/non-union	Union
23	Floor area on grade	8200 sq ft
24	Total site area	110% of item 23
25	HVAC requirements, tons	See 59/60 below
26	Building code class	Siesmic
27	Roof area	9600 sq ft
28	Type of construction contract	Fixed price
29	Length of partitions	1518
30	Connected power load	Unknown
31	Type of roofing	Shingled
32	Presence of sprinklers	No
33	Area of paving	37,5000 sq ft
34	Type of doors	1 hour
35	Type of interior partitions	Masonry
36	Area of landscaping	4200 sq ft
37	Number of occupants	136
38	Type of ceiling finish	Suspended plaster
39	R-value of exterior wall	11
40	Type of interior wall finish	Paint
41	Type of floor finish	Vinyl tile
42	Type of insulation	Panels/blown
43	Fire detectors required	Smoke alarms
44	Gross floor area	23,000 sq ft
45	Facility type	Barracks
46	Heating energy source	Steam
47	Cooling energy source	Chilled Water
48	Footprint area at grade	8200 sq ft
49	Facility perimeter length	600 sq ft
50	Stories above grade	3
51	Floor-to-floor height above grade	9 ft

Table 9 (Cont'd)

Number	Factor	Quantity
52	Stories below grade	0
53	Floor-to-depth height below grade	N/A
54	Piling depth	N/A
55	Number of stairwells	2
56	Average ceiling height	8 ft.
57	Percent full height partitions	99%
58	Plumbing Fixtures	180 pieces
59	Heating BTU	290,472 BTU
60	Cooling BTU	441,233 BTU
61	Sitework	1000 cu yd

Sequence Rules:

5.9 Steel sequence rule 5.9 is not appropriate for masonry structures since there will be no interior construction activity.

5.10 Steel sequence rule 5.10 is not appropriate for masonry structures since there will be no interior construction activity.

5.11 Steel sequence rule 5.11 is not appropriate for masonry structures since there will be no interior construction activity.

5.12 Start-to-start with Activity 10, "Mechanical Rough-In." Set the lead of Exterior Closure equal to 25 percent of the duration of Structure.

Source: Contractor interview/Team meetings. This sequence rule added to adapt the steel activity sequence to a masonry structure.

5.13 Finish-to-finish with Activity 10, "Mechanical Rough-In." Set the lag of Exterior Closure equal to 25 percent of the duration of Mechanical Rough-In.

Source: Contractor interview/Team meetings. This sequence rule added to adapt the steel activity sequence to a masonry structure.

5.14 Start-to-start with Activity 11, "Electrical Rough-In." Set the lead of Exterior Closure equal to 25 percent of the duration of Structure.

Source: Contractor interview/Team meetings. This sequence rule added to adapt the steel activity sequence to a masonry structure.

5.15 Finish-to-finish with Activity 11, "Electrical Rough-In." Set the lag of Exterior Closure equal to 25 percent of the duration of Electrical Rough-In.

Source: Contractor interview/Team meetings. This sequence rule added to adapt the steel activity sequence to a masonry structure.

Table 10

Activity Durations for Masonry Structure

Number	Description	Duration
1	Start Job	0
2	Site Preparation	4
3	Site Utilities	7
4	Foundation	4
5	Structure	70
6	Roofing	20
7	Exterior Closure	25
8	Equipment	0
9	Interior Construction	0
10	Mechanical Rough-in	5
11	Electrical Rough-in	28
12	Interior Finish	42
13	Site Improvements	10
14	Specialties/Furnishing	2
15	Mechanical Finish	10
16	Electrical Finish	15
17	End Job	0

Activity 6—Roofing

Sequence Rules:

6.6 If the number of stories above grade is less than three, then finish-to-start with Activity 12, "Interior Finish."

Source: Activity factors 5, "number of floors"; 50, "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

6.7 If the number of stories above grade is three or more, then start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 75 percent of the duration of Roofing.

Source: Activity factors 5, "number of floors;" 50, "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

6.8 If the number of stories above grade is three or more, then finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 75 percent of the duration of Interior Finish.

Source: Activity factors 5, "number of floors"; 50, "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

Activity 7—Exterior Closure

Sequence Rules:

7.9 If the number of stories above grade is less than three, then finish-to-start with Activity 12, "Interior Finish."

Source: Activity factors 5, "number of floors"; 50, "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

7.10 If the number of stories above grade is three or more, then start-to-start with Activity 12, "Interior Finish." Set the lead of Interior Finish equal to 50 percent of the duration of Exterior Closure.

Source: Activity factors 5, "number of floors"; 50 "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

7.11 If the number of stories above grade is three or more, then finish-to-finish with Activity 12, "Interior Finish." Set the lag of Interior Finish equal to 50 percent of the duration of Interior Finish.

Source: Activity factors 5, "number of floors"; 50, "stories above grade," 52, "stories below grade." This sequence rule modified to adapt the steel activity sequence to a masonry structure.

Activity 9—Interior Construction

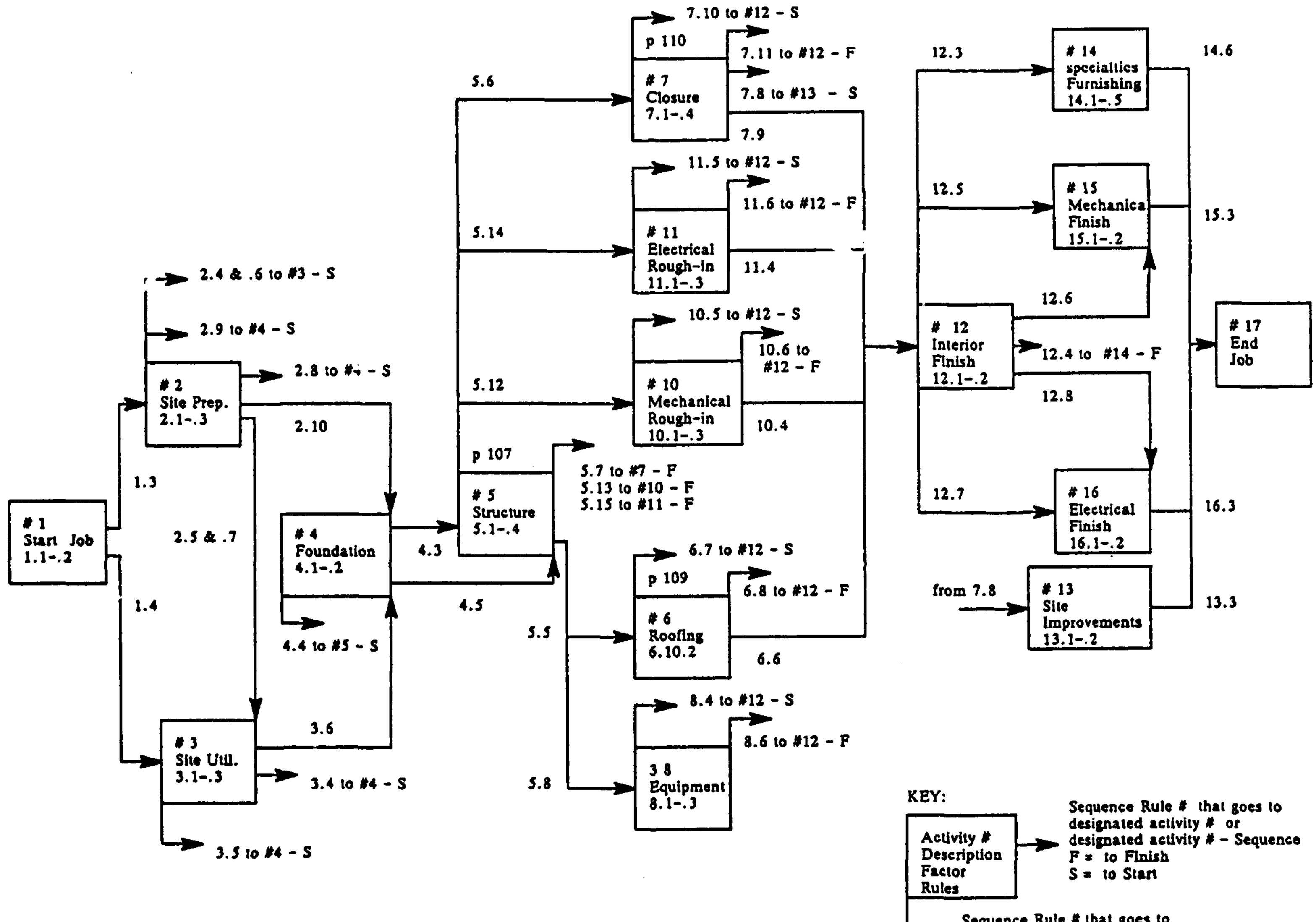
For the Barracks project with masonry construction, there is no interior construction since all interior walls are constructed with masonry. None of the steel activity factors apply to the masonry structure.

Interior floor slabs, in the masonry structure, are included in the structural activity. Reviewing the masonry structure reveals two key points regarding the application of factors to activity durations presented in this report: the importance of correct activity durations, and the potential flexibility of the activity factor model.

Accurate initial estimates of activity durations are an important factor in properly evaluating a contract duration. The duration of 70 days for Activity 5, "Structure," appears to be quite large given final completion date of the project. Even though the activity durations are important, they may not be critical given the flexibility of this approach.

The flexibility of the approach outlined in this report may allow a wide variety of interaction in a potential automated implementation. If an object-oriented approach were used for the implementation, the user may be able to quickly adapt a project for site-specific or unrealistic results. For example, if the user felt that the duration of the structural activity was too long based upon the initial result (Figure 9), then the duration could be reduced and the network would generate a modified schedule (Figure 10).

Another way that the user could easily interact with a potential automated system is to correct overly restrictive or unrealistic logic. For example, the roofing activity in the masonry structure is a major bottleneck since roofing, according to the sequence rules presented previously, may only start after the



The "p #" notation refers to the page numbers in "Evaluating Factors that Effect Project Duration", August 5, 1990.

Figure 9. Conditional Masonry Framed Network.

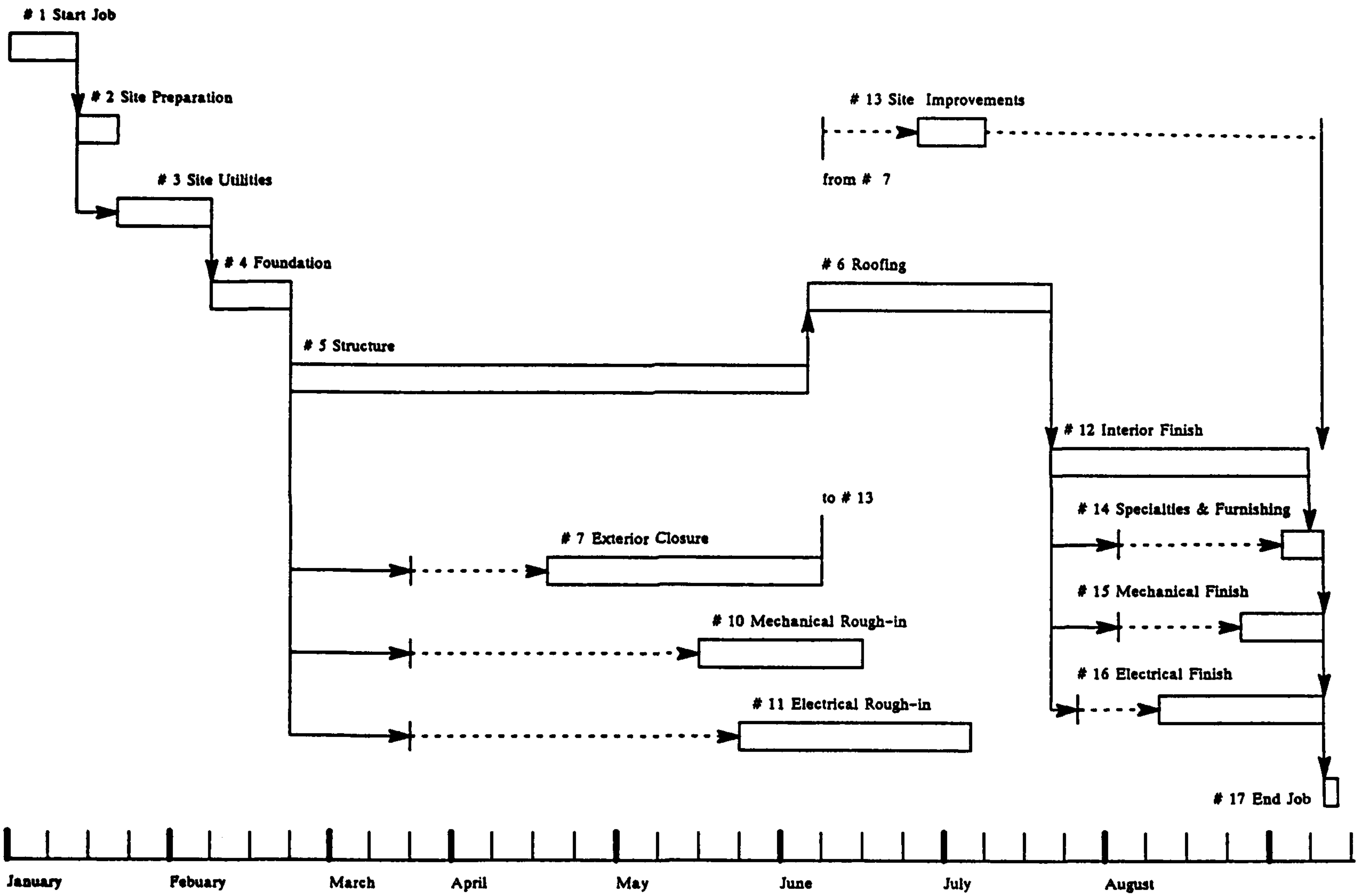


Figure 10. Masonry Schedule After Applying Factors.

structure has been completed. Using an object-oriented paradigm, the user would be able to quickly change the sequence between the structure and the roof to allow some roofing to proceed prior to the completion of the structure.

Another example of the way that the user could interact with a potentially automated system is to modify activity factors. For example, after reviewing the masonry schedule, the user may wish to modify the productivity activity factor. The productivity factor's initial setting is to remove all productivity delays; however, some productivity delays may be acceptable and may even reduce the project's duration. To change the productivity rule, the user may select menu options to modify a rule and select the appropriate amount of acceptable productivity delay. If an object-oriented system is developed, then the rule modification could be made at whatever level of detail the user thinks appropriate. The appropriate level of detail could be a single activity, a single project, a project type, or all projects.

Initial investigations into a practical implementation of such an object-oriented approach indicated that current AI programming environments such as Goldworks and KEE have the capabilities required.

Case Study Three: Cast-In-Place Concrete Structure

Although it was originally anticipated that the concrete structure sequence would be an intersection of the steel and the masonry sequences, the generic schedule for the concrete structure at this high level of abstraction is essentially the same as the steel structure. Both the concrete and steel structures provide a framework that is then filled in by interior partitions and closed off with exterior walls.

Two differences between the steel and concrete frames, from the point of view of the model presented in this report, relates to the more rapid delivery of concrete versus the long lead time of structural steel (factor rule 5.1, "Structure"); and differences in the weather delay factors that would be more heavily applied to the cast-in-place concrete structure (rule 5.3, "Structure").

While it may appear that the differences between the two types of structures may increase as the structure becomes taller, the differences may actually be very small, in terms of a preliminary schedule. It is a common practice to use high strength concrete and various admixtures to reduce the required minimum curing time. If additional delay between the concrete (Activity 5, "Structure"), and the following activities is needed, then sequence rules 5.7 through 5.10 may be modified.

Since the only differences between the steel and cast-in-place concrete are those discussed in the above paragraphs, complete activity descriptions and generic schedules were not produced for this case.

4 CONCLUSIONS

This study identified several additional factors that can unexpectedly extend construction activities: (1) work delays, (2) weather delays, and (3) productivity delays. These delay factors change the duration or timing of activities. The approach presented in this report uses conditional-sequence rules to model knowledge of the relation between activities. This eliminates the intermediate step that the user of existing CPM software must take, which must be modified for each project not exactly the same as the template of creating project templates, and which may then be used to provide preliminary project plans. This new approach may reduce the time required to produce preliminary schedules since the templates used already contain a significant amount of scheduling knowledge.

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APPENDIX: Deriving Activity Durations.

This appendix will briefly describe the process that was used to obtain activity durations from the CEG/CACES system. Although the process currently requires significant hand calculation and intensive data transfer, the work accomplished in this appendix may assist future development of interface programs for automatic generation of preliminary schedule activity durations.

The first step in the process of developing activity durations for this work was to develop the project factors required for the CEG system. These factors were listed in Table 1. The CEG produces a complete bill of materials for the project. This bill of materials is very detailed and is arranged according to a cost breakdown structure.

Using the bill of materials produced from the CEG, crews, equipment, and productivity factors were obtained from the CACES system. The crews provided from the CACES system are at a very low level since one pre-defined crew is provided for every time in the bill of materials. These pre-defined crews often differ only by a single tradesman or laborer.

To develop activity durations for this report from the CACES data (1) work items were combined into activities, then (2) similar crews were grouped together. Then since the activities contain several crews which could work concurrently were identified. Once more realistic crews were grouped together, the duration of the activity was recalculated to a "realistic" duration. For example, if a single masonry crew was to take 100 days to complete a task and 20 days was felt to be reasonable, then five masonry crews were used.

The process of translating CACES crews to realistic durations was based on heuristic reasoning. While heuristic approaches typically do not produce optimal results, the accuracy of results required of preliminary schedules need not be optimal. The heuristic approach used to develop activity durations from CEG/CACES data is consistent with the approach discussed in this report.

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